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Input Substitution and Productivity Change in Canadian Agriculture

by

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A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled Input Substitution and Productivity Change in Canadian Agriculture submitted by Tariq Saiful Islam in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

Dedication

To my parents.

Abstract

Various aspects of factor substitution and productivity change in Canadian and Western Canadian agriculture are examined in this study. The translog cost function, a function which belongs to the family of flexible forms and does not *a priori* restrict the value of elasticity of substitution, is used in the analysis of factor substitution. The analysis of changes in productivity in Canadian agriculture uses the Divisia index and other recent developments in the theory of productivity measurement.

Factor substitution in Canadian agriculture is analysed using derived demand functions corresponding to various modifications of the translog cost function to generate measures of elasticities of substitution between, and elasticities of demand for, the five major farm inputs of land, labour, machinery, fertilizer, and energy, and to examine the nature of technical change based on time series data for the years 1961 to 1978. The empirical estimates show considerable factor substitution and complementarity, inelastic demand for most farm inputs, and the rejection of the Cobb-Douglas specification. The empirical estimates also indicate the presence of both land- and labour-augmenting technical change, no decline in capital (machinery) for labour substitution after the 'energy crisis', and the rejection of the value added specification.

Estimates of both total factor productivity (TFP) and partial factor productivity (PFP) change are obtained using

the flexible weight Divisia indexing method. The estimates of the average annual increase of TFP in Canadian agriculture vary from 1.01 to 1.82 percent depending on the definition of the labour input (persons employed or manhours) used and the inclusion or the exclusion of the drought year of 1961. Western Canadian estimates of TFP based on manhours data are 2.48 and 1.70 percent per year for the 1961-78 and 1962-78 periods, respectively. The PFP estimates of the various input categories are also reported. The shortcomings of the PFP approach are evident from the empirical estimates which suggest that the productivity of capital and materials whose use rose over time have increased very slowly, while growth in the productivity of labour, the use of which has declined markedly, appears to be very high.

The distribution of the benefits of productivity growth are examined by estimating the terms of trade (ratio of the index of the price of output to the index of the price input) and returns to costs ratios (ratio of the index of the value of output to the value of inputs). The decline in the index of returns to costs implies a deterioration in farmers' economic position based on income from farm sources. The extent of such deterioration has been less in Western Canada which has registered higher productivity growth.

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I. INTRODUCTION

This study is concerned with the theoretical analysis and empirical measurement of input substitution and productivity growth in Canadian and Western Canadian agriculture over the period 1961 to 1978. In the analysis of changing input use, recent developments in production/cost theory and flexible functional forms are utilized to generate improved measures of the nature of factor substitution, the responsiveness of input demand to input prices, and the nature of technical change in the agricultural sector. In the analysis and measurement of productivity growth, improved flexible-weight indexing procedures are used to estimate productivity growth more accurately in Canadian and Western Canadian agriculture. The estimates of productivity advance are then combined with estimates of farmers' terms of trade to derive indications of benefits of productivity change in terms of income generated on the farm relative to costs.

A. Nature and Scope of the Problem

Changes in input use and productivity in Canadian agriculture are issues of continuing research and policy interest. The major forces of technological change and input substitution induced by relative factor price changes have led to important changes in the input mix in Canadian

agriculture. The labour input has been replaced by durable inputs such as machinery and by nondurable inputs such as fertilizer and energy. This transition in input use raises important questions with respect to the nature of factor substitution, input demand, and technical change as well as to the role of intermediate (nondurable) inputs and the impact of the 'energy crisis' on capital (machinery) for labour substitution. In this study, an attempt is made to shed light on these issues using the translog cost function approach.

Production is a process of transforming inputs into output. Productivity growth arises when the rate of growth of output exceeds the rate of growth of input. In Canadian agriculture, the important questions in this respect are whether productivity growth has slowed down in the 1970s and whether, and to what extent, the benefits of productivity growth have been eroded by the 'cost-price squeeze' (i.e., greater growth in input prices relative to output prices). This study tries to answer these questions using the Divisia indexing method and a reasonably comprehensive input classification. The Divisia indexing method has been advocated, among others, by Christensen (1975) and the U.S. Department of Agriculture (1980) for productivity study in agriculture. This procedure takes into consideration factor substitution and differs from the widely used fixed weight Laspeyres indexing procedure (used by Statistics Canada) which treats all subcomponents as perfect substitutes.

B. Research Objectives

The overall objective of this study is to obtain key indicators of factor substitution and productivity change in Canadian and Western Canadian agriculture using time series data from 1961 to 1978. The more specific objectives are:

1. To study substitutability and complementarity relations between different farm inputs by estimating the values of Allen partial elasticities of substitution (AES). The AES show how inputs substitute or complement one another in the production process.
2. To analyze changing input demand by estimating own and cross price elasticities of demand (ED) and to compare these with the restricted Cobb-Douglas values.
3. To examine the nature of technical change using both homothetic and nonhomothetic production structures.
4. To shed light on the expanding role of energy and energy-related farm inputs and the impact of rising energy prices on capital-labour (machinery-labour) substitution and the productivity of energy.
5. To estimate rates of growth in productivity using both total and partial factor productivity approaches and applying the flexible weight Divisia indexing method; to compare Divisia-based productivity growth rates with those based on Laspeyres procedures; and to analyze the distributional impacts of productivity change using estimates of changes in farmers' terms of trade and returns to costs ratios.

C. The Models, Input Classification, and Estimation Techniques

In this study, empirical estimates of key indicators of factor substitution and technical change are obtained using the transcendental logarithmic (translog) function proposed by Christensen, Jorgenson and Lau (1971). Based on recent developments in duality theory, a cost function approach is adopted and a translog cost function is used. The translog function belongs to the family of flexible forms and is more general than the widely used, but more restrictive, Cobb-Douglas (CD) and constant elasticity of substitution (CES) functions. The translog function does not place any *a priori* restriction on the value of the elasticity of substitution. Hence, it is suitable for studying both substitutability and complementarity between inputs in a multi-input production framework.

The input classification used in this study is designed to examine the role of both durable and nondurable inputs and to treat energy as a distinct farm input. Accordingly, the five inputs of land, labour, machinery, fertilizer, and energy are used in the analysis of factor substitution in Canadian agriculture. In the study of productivity change, the inputs of seeds and feeds are also included.

The key indicators of production structure are obtained from the estimated derived input demand equations corresponding to the translog cost function. These equations are estimated applying Zellner's seemingly unrelated

regression (Zellner, 1962) technique with appropriate restrictions. In this procedure, the set of equations are estimated as a system and interequation error term dependence is taken into account.

For estimating the parameters of the derived input demand functions and for constructing productivity indexes, the Divisia discrete indexing method is used. In recent years, the link between various functional forms and indexing methods has been investigated. It has been shown that the Divisia indexing method is appropriate for the translog function (Christensen, 1975; Diewert, 1976). Accordingly, the Divisia indexing procedure, which uses a flexible weighting scheme, is used in this study. The main features of the Divisia index in relation to the widely used fixed weight Laspeyres index are discussed in Chapters 4 and 6.

D. Organization of the Study

This study is divided into seven chapters. A description of changing input use in Canadian agriculture is given in Chapter 2. The theoretical models, input classification, and estimation procedures (for studying factor substitution) together with a brief survey of earlier flexible form studies in agriculture, are presented in Chapter 3. In Chapter 4, the methods of data construction and modification are discussed and the constructed indexes and cost shares are reported. Empirical estimates of factor

substitution, factor demand, the nature of technical change, and other aspects of the structure of production are derived and discussed in Chapter 5. Estimates of total and partial factor productivities and indicators of benefits of productivity growth are given in Chapter 6. Chapter 7 contains the summary, conclusions, and implications of this study.

II. CHANGING INPUT USE IN CANADIAN AGRICULTURE

The objective of this chapter is to provide a descriptive picture of changes in farm input use in Canadian agriculture during the 1960s and 1970s. This is done in terms of five major input categories: land, labour, machinery, fertilizer, and energy. This chapter is divided into three parts. In the first part, the main features of changing input use are described. In the second part, previous research work on input use in Canadian agriculture is briefly surveyed. In the third part, some simple tests of the relationship between input substitution and changing relative input prices are presented.

A. Major Input Categories

Land

The use of land as a farm input underwent some change in the 1960s and 1970s, particularly if one assesses land use change in terms of the 1976 census farm definition.[1] The total area in occupied farm land in Canada grew from 154.4 million acres in 1961 to 166.0 million acres in 1976. During this period, the area of improved land increased from 95.1 to 108.0 million acres. The increase in occupied farm land area was solely due to the increase in Western Canada where

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[1] For a discussion of land use changes in terms of the 1976 as opposed to the 1961 census farm definition, see Veeman (1981).

total area of occupied farm land rose from 125.5 million to 139.5 million acres between 1961 and 1976.[2] The area of improved land in Western Canada rose from 77.4 million acres in 1961 to 90.5 million acres in 1976, while that of unimproved land increased from 48.1 to 49.0 million acres over the same period. The foregoing data on land use are given in Table 2.1.

An important factor related to the use of land is the change in the size of farms. Between 1961 and 1976, the average size of farm rose from 359 to 499 acres in Canada. A more pronounced change took place in the acreage of improved land per farm in Canada, which rose from 215 to 323 acres. The increase in the average size of farm, together with the increased land value per acre, resulted in a substantial increase in the real capital value per holding ($36,500 in 1961 to $113,200 in 1976).

Labour

The salient feature of factor substitution in Canadian agriculture since World War II has been the continued move away from labour (at least prior to 1973). Capital-for-labour substitution occurred over time as the price of labour (human time) increased relative to the price of farm machinery. Between 1961 and 1978, the number of persons employed in agriculture declined from 681 thousand

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[2]During this period, there was a decline in occupied farm land in Eastern Canada.

Table 2.1: Area of Occupied Farm Land, Canada and Western Canada, 1961-76, Census Years

Year	Total	Improved	Unimproved	Improved	Unimproved
Canada		Million acres		Percent	Percent
1961	154.42	95.12	59.30	59.9	40.1
1966	161.68	102.55	59.13	62.1	37.9
1971	160.46	103.73	56.73	63.7	36.3
1976	165.98	108.00	57.98	64.6	35.4
Western Canada					
1961	125.44	77.36	48.06	61.6	38.3
1966	133.01	84.19	48.84	63.3	36.7
1971	134.24	86.88	47.36	64.7	35.3
1976	139.45	90.45	49.00	64.9	35.1

Note: These estimates are based on the 1976 census definition of a census farm.
Source: Agriculture Canada, *Selected Agricultural Statistics for Canada, 1978* (based, in turn, on Statistics Canada, *Census of Canada, Agriculture, 1976*).

to 478 thousand in Canada. A similar decline in the use of farm labour is also observed in Western Canada.

Agricultural labour can be divided into three classes--hired labour, unpaid family labour, and farm operators. Estimates of employment (persons employed) in these three classes of labour are presented in Table 2.2. Two important features emerge from Table 2.2. First, as indicated previously, there is a considerable decline in the absolute

Table 2.2: Employment of Agricultural Labour Force By Class of Workers, Canada, 1961-78, Selected Years (in thousands)

Year	Paid Hired	Unpaid Family Workers	Farm Operators	Total
1961	112	133	436	681
1966	98	110	336	544
1967	99	122	338	559
1968	99	128	319	546
1969	96	125	314	535
1970	99	116	296	511
1971	102	118	291	510
1972	99	110	273	481
1973	96	100	270	467
1974	99	103	271	473
1975	110	99	270	479
1976	143	90	241	474
1977	145	84	239	468
1978	133	93	252	478

Source: Agriculture Canada, *Selected Agricultural Statistics, 1980*.

use of labour between 1961 and 1978, although most of this decline had occurred by 1972. Second, the importance of paid hired labour increased and that of family labour declined during the period. This is a common feature in both Canadian and Western Canadian agriculture. In this study, much of the empirical work with respect to the labour input is conducted in terms of manhours data rather than persons employed data. Quantity indexes of farm manhours in Canadian and Western Canadian agriculture are presented in Chapter 6.

Machinery

The declining use of labour, the increasing size of farm, and the relatively low price of energy were factors associated with the growth in the use of machinery in Canadian agriculture during the 1960s and 1970s. Two key indicators are used to describe this process of mechanization. These are: (a) the deflated value of machinery per farm, and (b) the deflated value of machinery per worker, which are reported in Table 2.3.

The real value of machinery per farm increased by about 27 percent between 1961 and 1976. A faster growth was observed in the value of machinery per worker which more than doubled in real terms during this period. This increase in the face of declining use of labour suggests that more and better machinery was used. The use of more powerful and energy-intensive (and often energy-efficient) machinery is an important feature of increased mechanization of Canadian and Western Canadian agriculture during the period covered by this study.[3]

Fertilizer

Higher levels of output, given a slowly growing quantity of land under cultivation, were partially made possible through steady increase in the use of fertilizer in Canadian agriculture. The extent and the nature of changes

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[3]For a recent discussion on fuel prices and the demand for farm machinery, see Munro (1980).

Table 2.3: Deflated Value of Machinery on Farms and Per Agricultural Worker, 1961-76[1]

Year	Value of Machinery Per Farm Per Acre ($)	Value of Machinery on Farms Per Worker ($)
1961	29.79	3,767
1962	28.95	3,882
1963	29.95	4,025
1964	30.30	4,305
1965	31.40	5,442
1966	32.36	5,468
1967	33.37	5,555
1968	32.96	5,585
1969	32.50	5,618
1970	31.63	5,729
1971	30.85	5,581
1972	31.07	5,988
1973	32.03	6,386
1974	34.48	6,717
1975	35.86	6,884
1976	37.91	7,599

[1]Deflated by total farm machinery price index (1961=100)
Source: Agriculture Canada, *Statistics Relating to Farm Machinery in Canada, 1950-1976*

in fertilizer use are examined by considering both the total amount of fertilizer used and the average application rate (pounds per acre).

Estimates of consumption of fertilizer between 1961 and 1977 are given in Table 2.4. The use of fertilizer increased threefold in Canada while in Western Canada, the increase was seven times. A clearer picture of these changes can be

Table 2.4: Consumption of Commercial Fertilizer, Canada and Western Canada, 1960-61 to 1976-77

Year	Total Use in Thousand Tons		Pounds Per Cropped Acre	
	Canada	Western Canada	Canada	Western Canada
1960-61	1078	197	12.4	4.2
1961-62	1143	255	13.1	4.9
1962-63	1257	333	14.7	6.3
1963-64	1453	448	17.4	8.3
1964-65	1594	512	19.1	9.3
1965-66	1917	741	19.8	12.8
1966-67	2183	899	26.9	15.7
1967-68	2287	1008	29.4	17.9
1968-69	1896	638	25.5	12.0
1969-70	1886	522	28.4	11.0
1970-71	2109	723	27.7	12.5
1971-72	2175	833	29.7	14.2
1972-73	2875	1317	33.1	18.8
1974-75	2951	1439	41.3	27.2
1975-76	3063	1421	43.3	26.5
1976-77	3118	1473	43.3	27.1

Source: Agriculture Canada, *Fertilizer Statistical Bulletin, 1979.*

obtained by looking at the trend in application rate (use of fertilizer per cropped acre). Application rates of fertilizer for the principal field and vegetable crops in Canada and Western Canada are also presented in Table 2.4. There is clear indication of intensification of fertilizer use. The application rate rose from 12.4 to 43.3 pounds per acre in Canada while in Western Canada, the application rate rose from 4.2 to 27.1 pounds per cropped acre between 1960-61 and 1976-77. It can be seen from Table 2.4 that

although the increase (in percentage terms) in application rate has been greater in Western Canada, the quantity of fertilizer applied per acre remains much lower.

Energy

The direct use of energy increased during the period 1961 to 1978. In this study, energy is defined in terms of the direct use of petroleum products and electricity. The direct use of fuel and lubricants constitutes two-thirds of the overall use of energy in Canadian agriculture while the indirect use of energy in the production of fertilizer, pesticides, and machinery, and in other uses such as transportation, accounts for the balance. Estimates of the distribution of energy use in Canadian farming are given in Table 2.5.

Agriculture is an important consumer of motive fuel such as gasoline and diesel fuel. Of these two, the consumption of diesel fuel has grown more rapidly and this trend is likely to continue as diesel engines continue to replace gasoline engines. In Table 2.6, the levels of consumption and the percentage change in the use of motor gasoline and diesel fuel are presented. Quantity indexes of energy use in Canadian and Western Canadian agriculture are reported and discussed in Chapter 6.

Table 2.5: Distribution of Energy Use in Canadian Farming

Fuel and lubricants	67%
Fertilizer and pesticides	17%
Machinery	5%
Other	11%

Source: I.F. Furniss, "The Energy Demands of Agriculture," *Canadian Farm Economics* 13(June), 1978.

Table 2.6: Net Farm Sales of Motor Gasoline and Diesel Fuel in Canada, 1965 to 1977 (million imperial gallons)

Year	Motor Gasoline	% Change	Diesel Fuel	% Change
1965	592	-	215	-
1966	601	1.5	218	1.4
1967	614	2.2	223	2.2
1968	641	4.4	232	4.4
1969	615	-4.0	215	-7.4
1970	642	4.3	200	-7.2
1971	647	0.7	213	6.6
1972	660	2.0	228	6.8
1973	684	3.6	248	9.1
1975	733	7.8	304	12.4
1976	720	-1.8	331	8.8
1977	718	-0.3	339	2.4

Source: D.R. Morris, "Energy," in Agriculture Canada, *Market Commentary - Farm Inputs, 1979.*

B. A Survey of Selected Earlier Studies of Input Use

A study of factor substitution and productivity in Canadian agriculture was conducted by Shute (1975). The study, which updated earlier works by Furniss (1970), covered the period from 1961 to 1974 and contained quantity indexes and cost shares of various farm inputs. These figures showed continued decline in the use of labour, and increases in the use of farm machinery, fertilizer, and energy. Shute did not use any specific model to obtain estimates of the key indicators of factor demand and factor substitution. Nonetheless, the information contained in Shute's paper provides a fairly clear picture of changing farm input use in Canadian agriculture prior to the 'energy crisis'. Shute's analysis of productivity change is discussed in Chapter 6.

Furtan and Lee (1977) studied changing land-labour ratios in the Saskatchewan wheat economy. They adopted the framework proposed by Hayami and Ruttan (1971) who suggested that if technology was adopted due to changes in relative factor prices, the land-labour ratio should be a function of relative factor prices. Using this hypothesis, Furtan and Lee expressed the land-labour ratio as a function of the price of machinery, the farm fuel price, and the price of land, each relative to the price of farm labour. Their estimated function was based on Saskatchewan data for 1961 to 1970.

Furtan and Lee concluded that the relative prices of these input categories explained most of the change in the land-labour ratio. They inferred that the increase in the size of farm was largely due to the relatively low price of machines and fuels compared to the price of labour. Since machinery could substitute for labour, the changing factor price ratio between machinery and labour encouraged substitution between these two inputs. The Saskatchewan wheat economy accordingly adopted labour-augmenting capital.

In a recent paper, Perkins (1980) surveyed trends in farm input costs and incomes in Canada. Perkins' observations are: (a) since 1974, farm product prices have increased less than farm input prices and the increase in farm product prices since then has also been less than the increase in the consumer price index; (b) consumption of gasoline and diesel fuel by the agricultural sector appears to have stabilized in recent years; (c) hired farm labour continued to replace unpaid family labour, an indication of progressive commercialization of Canadian agriculture; and (d) the share of fertilizer in total cost rose more rapidly than that of other inputs. These observations provide a good background to many of the issues which are examined in our study of factor substitution and productivity.

C. Factor Use and Factor Prices

The descriptive indicators of input use presented above can be combined with input price information to provide some simple tests of the induced innovation hypothesis. These tests throw further light on the direction of changing input use and technical change in Canadian agriculture as induced by changing relative factor prices.

In recent years, induced innovation and factor substitution in agriculture have been examined (Hayami and Ruttan, 1971; Ruttan, Binswanger, Hayami, Wade, and Weber, 1978). These studies used the concepts of biological technology and mechanical technology. The former refers to the increased use of fertilizer and other chemical inputs to raise the productivity of land, while the latter refers to to the use of machinery to substitute for labour and augment its productivity.

Ruttan *et al.* (1978) provide a framework to study biological and mechanical technology in terms of factor prices and factor use. They examined changes in fertilizer use per acre of land (F/N) as a proxy for biological technical advance, and changes in machinery per worker (M/L) and land per worker (N/L) as proxies for mechanical technical advance. These factor use ratios were regressed on their corresponding factor price ratios for Japan, Germany, Denmark, France, United Kingdom, and the United States. Applying their framework, the following hypotheses were tested for Canadian agriculture using time series data for

the period 1961 to 1978:[4]

1. A fall in the price of fertilizer, P(F), relative to the price of land, P(N), increases fertilizer application rate per acre. Hence, (F/N) and P(F)/P(N) are expected to be negatively related.
2. Machinery per unit of labour, (M/L), increases when the price of machinery, P(M), falls relative to the price of labour, P(L). Accordingly, a negative relationship is anticipated between (M/L) and and P(M)/P(L).
3. A fall in the price of land, P(N), relative to the price of labour, P(L), increases land per unit of labour, (N/L), implying a negative relationship between (N/L) and P(N)/P(L).

The estimated coefficients corresponding to hypotheses 1, 2, and 3 are reported in Table 2.7. Two of the three relationships were found to apply to Canadian agriculture. The fertilizer application rate was negatively related to the price of fertilizer relative to the price of land. This confirms hypothesis 1 and indicates the presence of biological technical change. Increase in machinery per worker was also negatively related to the machinery-labour price ratio, implying mechanical technical change. The

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[4] Besides these direct relationships which associate ratios of input quantities with their corresponding relative prices, Ruttan *et al.* also examined indirect relationships between the ratio of the uses of two inputs and the ratio of the price of one of these inputs and the price of some other input. Evidence on these indirect relationships was not always conclusive.

Table 2.7: Relationships Between Fertilizer Use Per Acre, Land Per Worker, Machinery Per Worker and Their Relative Prices in Canada for the Period 1961 to 1978

	Coefficients of Price			
Dependent Variable	Fertilizer in Relation to Land, P(F)/P(N)	Machinery in Relation to Labour, P(M)/P(L)	Land in Relation to Labour, P(N)/P(L)	R^2
Fertilizer Per Unit of Land, (F/N)	-1.10** (-5.79)			0.67
Machinery Per Worker, (M/L)		-1.21** (-6.84)		0.74
Land Per Worker, (N/L)			0.56** (3.34)	0.41

Note: Two asterisks denote significance of the estimated coefficient at the 1 percent level. The t-values are given in parentheses.

expected negative relationship between land per worker and the price ratio of land to labour, which would have added further support to the presence of mechanical technical change, did not hold for Canada.

The above simple tests involving changes in input use ratios and changes in relative input price ratios indicate that the Canadian agricultural sector did respond to changes in relative factor prices. The estimates also indicate the

presence of both biological and mechanical technical change. A more detailed treatment of input use in terms of factor substitution, factor demand, and technical change is given in Chapter 5.

III. THE TRANSLOG MODEL OF FACTOR SUBSTITUTION: REVIEW AND SPECIFICATION

The objective of this chapter is to specify the theoretical and empirical framework which will be used to analyze changing use of major inputs in Canadian agriculture. Typically, the analysis of production relations has been carried out using a production function approach setting output as a function of quantities of inputs and using functional forms with restrictive specification of factor substitution. Recent developments in production economics suggest that the characteristics of production relations might be more usefully studied by using a cost function approach and by using functional forms which are less restrictive in nature. (Diewert, 1974; Binswanger, 1974). This study makes use of these developments.

In this chapter, the rationale for choosing a flexible form and the cost function approach is discussed. A basic translog cost function model, with some variations, is specified for the agricultural sector in Canada and Western Canada. The econometric procedure for its empirical implementation is outlined. The chapter concludes with a brief survey of flexible form studies in agriculture.

A. Production and Cost Relationships

There are two general types of functional forms which can be used in a study of changing input use--those which are bounded by *a priori* restrictons and those which are not. The former type includes the Cobb-Douglas (CD), the Constant Elasticity of Substitution (CES) and the Leontief functions while the latter type includes various flexible forms.[1]

The flexible forms are so termed because they do not impose any *a priori* restriction on the value of the elasticities of substitution (ES). These forms are logical extensions of the *a priori* restricted forms. This can be seen by considering limitations of the CD and the CES functions and by examining the way in which the flexible forms attempt to overcome these limitations. The specification of the CD function restricts the value of ES to unity which, in turn, implies constancy of factor shares. The CES function can be used to derive values of ES other than one and can link movements of factor shares with magnitudes of factor substitution, but it is a highly restrictive form when dealing with more than two inputs. Further, the CES function cannot generate negative values of ES coefficients and thus cannot be used to examine complementarity, a relationship which is likely to exist among some pairs of farm inputs. In contrast, the Leontief function (i.e., the input-output model) implies no

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[1]Detailed discussion of flexible forms and duality is given in Fuss and McFadden (1978) and Blackorby, Primont and Russell (1978).

possibility of input substitution with the consequent ES of zero. The flexible forms, on the other hand, allow for any value of ES between two inputs and can consider a larger number of inputs. Thus, these forms provide more adequate tools for analyzing multi-input relationships in that they allow for both substitutability and complementarity between inputs in the production process.

The development of the flexible forms took place during the 1970s. Christensen, Jorgenson and Lau (1971) proposed the transcendental logarithmic (translog) function. In the same year, Diewert (1971) advanced the generalized Leontief function. Two years later, Diewert (1973) proposed the generalized Cobb-Douglas function. The following year another flexible form--the quadratic function--was proposed by Lau (1974) and, in 1978, the generalized concave function was advanced by McFadden (1978). A list of these functional forms is available in Fuss, McFadden and Mundlak (1978).

The various flexible forms mentioned above have one important mathematical property in common--each of them can provide a second order local approximation to any twice differentiable production, cost or utility function. The implications of this important property in connection with the question of choosing among flexible forms were explained by Berndt, Darrough and Diewert (1977: 117-118) who said:

> We are not able to discriminate and choose among the three forms on theoretical grounds, for each of the forms can provide a second order differential approximation to an arbitrary twice differentiable reciprocal indirect utility function which is

> linearly homogeneous along the ray of equal prices. *A priori* we are also unable to choose among flexible forms on econometric grounds, for estimation in each case involves the same dependent variables, the same number of free parameters and the maximization of similar likelihood functions. In particular, we cannot employ classical test procedures to choose among the three models, for the forms are non-nested, i.e., one is not a specified limiting case of the other. We can of course compare the models *a posteriori*, examine the various estimated parameters and elasticities, and then discriminate among them in terms of conformity with our prior notions.

Although some prior grounds such as the expected substitutability between machinery and labour in the agricultural sector of developed countries are clear, other relationships in a multi-input framework cannot be clearly anticipated and, therefore, the criterion of discriminating on the basis of prior notions appears both inadequate and incomplete.

Nonetheless, some authors have attempted to discriminate between various flexible forms in specific applications. Berndt, Darrough, and Diewert (1977) compared the translog, generalized Leontief and generalized Cobb-Douglas functions on the basis of their conformity with prior information and on the basis of a Baysian testing technique. These authors concluded that the translog function performed the best. Kiefer (1975), using a Box-Cox (1964) transformation, discriminated between the translog and the generalized Leontief functions and concluded that the former had performed better. In a more recent study, Appelbaum (1979) used parametric testing procedures and found the generalized Leontief and the square rooted

quadratic to be preferable to the translog function for the U.S. manufacturing data used in Berndt and Christensen (1974).

It is clear that the issue of choosing among flexible forms is far from settled. The studies mentioned above were applied to different manufacturing data and the results are thus neither strictly comparable nor conclusive. In studies of agriculture, available empirical evidence is too scanty to indicate strong reasons for choosing one flexible form over the others. The studies by Binswanger (1973), Brown (1978) and Chotigeat (1978) all applied the translog function. For the sake of comparability and on the basis of the consistently meaningful results which have been obtained by using the translog function, this functional form is chosen for our study.

Production relationships can be examined by using either a production or cost function approach. The former approach, which has dominated research, suffers from several limitations. The major limitaion is the existence of high levels of multicollinearity among input variables which results in imprecise estimates of production function coefficients.[2] These problems can be reduced by using a cost function rather than a production function to estimate production relationships. The cost function approach is based on Shephard's duality theorem (Shephard, 1953). A detailed discussion of duality can be found in Diewert

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[2]For a more detailed discussion, see Binswanger (1974).

(1974) and Blackorby, Primont and Russell (1978).

The Translog Cost Function Approach

Let us specify a production function which relates the flow of output Y to various input quantities Q(1), Q(2),...,Q(Z). In its general form, the production function can be written as:

$$Y = Y[Q(1), Q(2), \ldots., Q(Z)] \quad (3.1)$$

where Q(1),Q(2),...,Q(Z)) are factor quantities. It is assumed that (3.1) is twice differentiable. Then corresponding to (3.1) there exists, by Shephard's lemma,[3] a cost function which reflects the production technology. The cost function can be written as:

$$C = C[P(1), P(2), \ldots., P(Z), Y] \quad (3.2)$$

where C is total cost and P(1),P(2),...,P(Z) are input prices of Q(1),Q(2),...,Q(Z) respectively.

Empirical estimation of (3.2) necessitates specification of a specific functional form. In this study, the translog function advanced by Christensen, Jorgenson and Lau (1973) is applied. The translog function, like other flexible forms, does not place any *a priori* restriction on elasticity of substitution values.

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[3] Shephard's lemma implies that the first derivative of the cost function with respect to the price of an input is equal to the demand for that input.

The Translog Single Output Model

The translog cost function in its usual form can be written as:

$$\ln C = a_o + a_Y \ln Y + 1/2\ \gamma_{YY} (\ln Y)^2 + \sum_i a_i \ln P_i$$

$$+ 1/2 \sum_{ij}\sum \gamma_{ij} \ln P_i \ln P_j + \sum b_{Yi} \ln Y \ln P_i \qquad (3.3)$$

where C is total cost of production, Y is aggregate output, and P's are input prices. In (3.3) above, the possibility of augmented technical change has not been incorporated. When (3.3) is modified to include technical change by including time (t) as an argument,[4] then:

$$\ln C = a_o + a_Y \ln Y + 1/2\ \gamma_{YY} (\ln Y)^2 + \sum_i a_i \ln P_i$$

$$+ 1/2 \sum_{ij}\sum \gamma_{ij} \ln P_i \ln P_j + \sum_i b_{Yi} \ln Y \ln P_i$$

$$+ \phi_t t + 1/2\ \phi_{tt} t^2 + \phi_{tY} t \ln Y + \sum_i \phi_{tP_i} t \ln P_i \qquad (3.4)$$

----

[4] This formulation specifies technical change at a constant rate. Hence it can only provide a description of the existence and direction of technical change but cannot provide an exact measure. See Binswanger (1974) and Lopez (1980).

Cost-minimizing derived demand equations for the various inputs are obtained from (3.4) by logarithmically differentiating this function with respect to input prices via Shephard's lemma (1953). The derived demand equations obtained from this process can be written as:

$$\frac{\partial \ln C}{\partial \ln P_i} = S_i = a_i + \sum_j^n \gamma_{ij} \ln P_j + b_{Yi} \ln Y + \phi_{tP_i} t \qquad (3.5)$$

where S(i) is the share of the i-th input in total cost.[5] Satisfaction of the adding up criterion(i.e., sum of the cost shares equals unity), zeroth degree homogeneity of the cost function in prices, and the usual properties of neoclassical production theory leads to the imposition of the following restrictions on (3.5):

$$\left.\begin{aligned} \sum_i a_i &= 1 \\ \sum_i \gamma_{ij} &= 0 \\ \sum_i b_{Yi} &= 0 \\ \sum_i \phi_{tP_i} &= 0 \end{aligned}\right\} \quad \text{(adding-up criterion)}$$

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[5] Since textform procedures do not yet allow for letter subscripts, S(i) is used to designate S subscript i. This method is followed throughout this dissertation.

$$\left.\begin{aligned} \sum_j \gamma_{ij} &= 0 \\ \gamma_{ij} &= \gamma_{ji} \end{aligned}\right\} \quad \begin{aligned} &\text{(zero homogeneity in prices)} \\ &\text{(symmetry)} \end{aligned} \tag{3.6}$$

The set of equations (3.5) has been stated in general terms. This set can reflect different production structures depending on the restrictions which are placed on it. It generates (a) a nonhomothetic structure with augmented technical change when no restriction but (3.6) is placed on it, (b) a nonhomothetic structure without augmented technical change when all coefficients of time are set equal to zero, i.e., when t is excluded as an argument in the cost function, and (c) a homothetic structure with augmented technical change when all coefficients of output are set equal to zero, i.e., when scale effects are ignored. (This latter restriction should not be confused with the restriction that the sum of all coefficients of output is equal to zero, which does not in itself imply a homothetic

structure).[6] All these three variations of the single output model are used in this study.

The Translog Joint Output Model

In production and cost function studies, attention is given to disaggregation of inputs, and output is frequently treated as a homogeneous product. However, output is often composed of several distinct components. Procedures of simultaneous modelling of different types of output have only recently been developed and applied (Burgess, 1974; Brown, Caves and Christensen, 1975; Fuss and Waverman, 1975; Brown, 1978). Brown (1978) applied a joint output model (crops and livestock) to U.S. agriculture using the translog function. Following Brown, the joint-output translog function for n outputs and m inputs which incorporates technical change is:

$$\ln C = a_o + \sum_j^n a_j \ln Y_j + \sum_i^m b_i \ln P_i$$

$$+ 1/2 \sum_i^n \sum_j^n d_{ij} \ln Y_i \ln Y_j + 1/2 \sum_i^m \sum_j^m w_{ij} \ln P_i \ln P_j$$

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[6] The coefficients of output in the system of derived demand (share) equations only show the extent of nonhomotheticity. These do not provide an estimate of returns to scale. In order to obtain an estimate of returns to scale, it is necessary to estimate the cost function as well. See Fuss (1977) and Fuss (1980, personal correspondence to the author).

$$+ \sum_{i}^{n}\sum_{j}^{m} f_{ij} \ln Y_j \ln P_i + 1/2\, \phi_{tt} t^2 + \phi_t t$$

$$+ \sum_i \phi_{tP_i} \ln P_i + \sum_j \phi_{tY_j} t \ln Y_j \qquad (3.7)$$

The homothetic derived demand equations corresponding to (3.7) are:

$$\frac{\partial \ln C}{\partial \ln P_i} = S_i = b_i + \sum_j^m w_{ij} \ln P_j + \sum_j^n f_{ij} \ln Y_j + \phi_{tP_i} t \qquad (3.8)$$

where S(i) denotes the share of the i-th input in total cost and Y(i) (i = 1, ..., n) are various outputs. The following restrictions are placed on (3.8) to conform to linear homogeneity in factor prices and the usual neoclassical properties:

$$\left.\begin{array}{ll}\sum_i b_i & = 1 \\ \sum_i w_{ij} & = 0 \\ \sum_i f_{ij} & = 0 \\ \sum_i \phi_{tP_i} & = 0\end{array}\right\} \quad \text{(adding-up criterion)}$$

$$\left.\sum_j w_{ij} = 0 \right\} \quad \text{(zero homogeneity in prices)}$$

$$\left. w_{ij} = w_{ji} \right\} \quad \text{(symmetry)} \tag{3.9}$$

In this study, the joint output translog cost function is applied using two distinct outputs of crops and livestock. This output classification is similar to the one used by Brown (1978), but the input classification of our study is different.

Elasticities of Substitution and Demand

Estimates of elasticities of substitution and demand can be obtained from the derived demand equations. The elasticity of substitution shows the ease with which one factor is substituted for another in response to changes in their respective prices and can be expressed as the ratio of the percentage change in the ratio of the inputs to the percentage change in the marginal rate of substitution between them. The estimated values of the coefficients of (the natural logarithms of) input prices in the derived demand equations form the basis for these estimates. The gamma coefficients do not have any clear economic meaning

but are translated into Allen partial elasticities of substitution (AES) and price elasticities of factor demand (ED). Following Uzawa (1962), the expression for AES between any two inputs i and j is:

$$\sigma_{ij} = \frac{C_i \; C_{ij}}{C_i \; C_j}$$

where $C_i = \partial C/\partial P_i$

and $C_{ij} = \partial^2 C/(\partial P_i \; \partial P_j)$

(3.10)

where sigma(ij) denotes AES between inputs i and j. By definition, the elasticities of substitution between any two inputs are symmetric. The expression (3.10) above is a general one. For the translog function, the AES are given by:

$$\sigma_{ii} = \frac{\gamma_{ii} + S_i^{\,2} - S_i}{S_i^{\,2}}$$

$$\sigma_{ij} = \frac{\gamma_{ij} + S_i \; S_j}{S_i S_j}$$

(3.11)

The AES derived from (3.11) are not constrained to be constant, as in the CES function, but may vary with changes in the values of cost shares. This property is used when the values of AES for different subperiods are obtained in this

study.

The price elasticities of input demand (ED) with respect to own and other prices are also derived from the estimated gamma coefficients. The concepts of AES and ED are also closely related. Following Allen (1938):

$$(ED)_{ij} = S_j \sigma_{ij}$$

$$(ED)_{ii} = S_i \sigma_{ii} \tag{3.12}$$

where E denotes the elasticities of input demand. The share of the i-th input need not be equal to the share of the j-th input. Therefore, in general, cross price elasticities are not equal. The relationships between the AES and ED make it possible to conduct an integrated study of factor demand and factor substitution using this model.

Comparison with Cobb-Douglas Estimates

The translog function reduces to the CD function when unitary elasticity of substitution is invoked by specifying that each gamma coefficient is equal to zero. Estimates of own and cross price elasticities of input demand under these restrictions enables comparison of these with the estimates obtained by using the translog function. In this study, the estimates of the elasticities of demand corresponding to the CD specification are also provided. The implications of the CD estimates and their limitations are discussed in Chapter 5. In the case of the Cobb-Douglas specification, ED are

given by:

$$(ED)_{ij} = S_j$$

$$(ED)_{ii} = S_i \tag{3.13}$$

B. A Survey of Flexible Form Studies in Agriculture

Binswanger (1973) first applied the translog function to agriculture in a study of factor substitution and technical change in U.S. agriculture. He applied a homothetic cost function and considered five inputs. Substitution relationships were found for the input pairs land-labour, land-machinery, land-fertilizer, labour-machinery, labour-other, machinery-other and fertilizer-other while complementarity relationships were observed for land-other, labour-fertilizer and machinery-fertilizer pairs. Most estimates of elasticities of substitution (ES) were different from unity which implies rejection of the Cobb-Douglas specification. The presence of complementarity also led to the rejection of the CES specification. Binswanger also found evidence of biased technical change in U.S. agriculture.

Brown (1978) studied factor substitution and factor productivity in U.S. agriculture using a homothetic translog cost function and experimented with several model variations including augmented technical change, treatment of fixity of inputs, and joint-outputs. In the econometric analysis of

factor substitution, the study used three inputs--capital, hired labour, and materials. For the 1947-60 period, Brown found capital-labour and labour-material pairs to be substitutes while capital and material were found to be complements. For the 1961 to 1974 period, each of the three input pairs was shown to involve a substitution relationship. Brown, as had Binswanger, found clear evidence of factor augmenting technical change in U.S. agriculture. In general, his estimates of ES led to the rejection of the CD and the CES specifications.

Chotigeat (1978) has provided one of the few applications of the translog function to the agricultural sector of a developing country. He studied factor substitution and input demand in Thai agriculture using a homothetic translog production function. Chotigeat used three inputs--capital, labour, and fertilizer. He obtained a substitution relationship between capital and fertilizer and between capital and labour and a relationship of complementarity between fertilizer and labour for the period 1952 to 1962. For the subsequent period 1963 to 1972, all three pairs were found to be substitutes. The ES values were, in general, different from the CD specification of unitary elasticity of substitution. The study did not consider the question of technical change in Thai agriculture.

Lopez (1980) used the generalized Leontief function to study factor substitution in Canadian agriculture. He

considered the four inputs of labour, capital, land and structures, and intermediate inputs. He used a nonhomothetic cost function formulation to allow for possible scale effects and also incorporated technical change. This study found that all four inputs were substitutes. Lopez found strong evidence of nonhomotheticity although there was not significant evidence of factor-augmenting technical change. An explanation of this latter feature was thought to perhaps be due to the nonhomothetic structure which was used.

C. Specification of Inputs in the Model

The derived demand equations corresponding to the translog cost function--(3.5) for the single output model and (3.8) for the joint output model--for Canadian and Western Canadian agriculture are estimated using an input classification which consists of land, labour, machinery, fertilizer, and energy. The input classification is designed to study the role of energy and other major durable and nondurable farm inputs. These inputs consist of the following subcomponents: land--both improved and unimproved; labour--hired, unpaid family, and farm operators; machinery--tractors, combines, and ploughs; fertilizer--mixtures and materials; and energy--petroleum products and electricity. Explicit specification of these inputs is discussed in Chapter 4. Denoting these five inputs of land, labour, machinery, fertilizer, and energy by N, L, M, F, and E, respectively, the production and cost functions

given by (3.1) and (3.2) above can be rewritten as:

$$Y = Y[Q(N), Q(L), Q(M), Q(F), Q(E)] \tag{3.14}$$

$$C = C[P(N), P(L), P(M), P(F), P(E), Y] \tag{3.15}$$

Proper classification of farm inputs is crucial to the analysis of changes in input use over time. A brief reference to input classifications used in earlier studies and a comparison with our classification is made in Table 3.1.

Table 3.1: Farm Input Classifications in Various Flexible Form Studies in Agriculture

Author	Country	Inputs
Binswanger (1973)	U.S.A.	Land, labour, machinery, fertilizer, other.
Brown (1978)	U.S.A.	Capital, labour, materials.
Chotigeat (1978)	Thailand	Capital, labour, fertilizer.
Lopez (1980)	Canada	Land, labour, capital, intermediate inputs.
Our Study	Canada, Western Canada	Land, labour, machinery, fertilizer, energy.

It can be seen from Table 3.1 that Binswanger's study and this study treat as separate the use of fertilizer and machinery, inputs which incorporate important biochemical and mechanical innovations. In other studies, the level of aggregation was even higher. Brown (1978) used a three input structure of capital, labour (hired) and material in his study of U.S. agriculture. Chotigeat (1978) studied factor substitution in Thai agriculture using capital, labour, and fertilizer as the farm inputs. In a recent study on Canadian agriculture, Lopez (1980) used a four input classification of land and structures, labour, capital, and intermediate inputs.

In none of the previous studies was energy treated as a separate input. The importance of energy and its rising price indicate separate treatment of this input which has been extensively dealt with in manufacturing studies. The classification of inputs in this study has been designed to investigate separately the role of energy in relation to land, labour, machinery, and fertilizer.

Although theoretically the flexible forms can consider any number of inputs, practical considerations limit the number of inputs which can be meaningfully considered. Fuss (1977: 89-90) illustrates this aspect by saying:

> However, application of the many-input case is hampered by the fact that the estimating equations are usually linear in simple monotonic functions of input prices and are plagued by multicollinearity problems. These problems are especially common in time series analysis.

The five inputs which are used in analyzing factor substitution in this study account for approximately 85% of all farm expenses in Canada. The sixth input--seeds and feeds--is not considered in the study of factor substitution, but is included in the analysis of productivity where the problems mentioned above do not arise.

D. Estimation Procedures

In the usual two-input neoclassical model, changes in relative input prices eventually lead to one input being substituted for the other. In a multi-input model, a change in relative prices generates a set of adjustment possibilities. For example, with the five inputs of this study (land, labour, machinery, fertilizer, and energy) if, say, the price of fertilizer increases, this may lead to a reduction in fertilizer use and to changes in the use of other inputs depending on the prices of other inputs and substitutability and complementarity relationships between inputs. In such situations, it is necessary to study the spectrum of simultaneous changes. Therefore, econometric estimation of the derived demand equations using a simultaneous approach is desirable. If the derived demand equations are estimated using ordinary least squares methods, estimators will be unbiased but will not be

efficient.[7] An appropriate econometric approach when all prices are treated as exogeneous is Zellner's Seemingly Unrelated Regression technique (Zellner, 1962). This procedure takes into consideration dependence between error terms across equations and generates both unbiased and efficient estimators.

In estimating the set of equations (3.5) and (3.8), it is necessary to have a stochastic framework; thus, a disturbance term, which is assumed to be normally distributed, is added to each of the equations in (3.5) and (3.8). Since the sum of the cost shares equals unity, it is necessary to delete one equation to avoid over-identification. But the estimates obtained are not invariant to the equation deleted. To overcome this problem, the study uses an iterative method to generate estimates which are invariant to the equation deleted. The share equations are estimated using the computer program SHAZAM recently developed by White (1979).

E. Summary

This chapter gave a review of previous studies and outlined various modifications of the translog cost function. The survey of various flexible forms in agriculture shows that the use of these models has been largely vindicated. Nonetheless, there does seem to be a

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[7] See Kmenta (1971: 518-519) for a good exposition of this point.

need to extend the basic flexible form approaches to account for : (a) more explicit treatment of energy, (b) the testing of homothetic and nonhomothetic production structures, and (c) the study of joint-output production. In this study, the translog cost function incorporating these modifications is used to examine changing input use in Canadian and Western Canadian agriculture over the period from 1961 to 1978.

IV. THE DATA AND MODIFICATIONS

This chapter is concerned with the manipulation of data into the form necessary for estimating the parameters of the models specified in Chapter 3. To estimate the coefficients of the derived input demand equations corresponding to the translog function, input cost shares, price indexes for the various inputs, and indexes of all output and of crops and livestock separately are needed. In the first part of this chapter, data classifications and definitions are given. The construction of the various indexes is then outlined. In the last part of this chapter, the resulting indexes and cost shares for Canada and Western Canada are presented and briefly discussed.

A. The Cost Data

Farm inputs can be broadly divided into the two categories of labour and nonlabour inputs. The latter can be further divided into durable and nondurable inputs. Nondurable inputs are also termed intermediate inputs, materials, or purchased inputs and include fertilizer, direct energy inputs, and seeds and feeds. The main characteristic of nondurable inputs is that these can be used only once. Thus, the unit cost of an intermediate input is equal to the unit price the farmer pays for it.

Durable inputs, on the other hand, are not used up after one use. This category includes land, buildings, and

machinery. Durable inputs are treated as stocks which generate flows of services over time. Two costs are attributable to these inputs when expenditures on them are computed. One is opportunity cost, i.e., the return that is forgone by investing in these inputs, and the other is depreciation which can be viewed as that part of the durable input which "wears out" as it is used during a period of time.[1] It is customary to attach no depreciation to land while in the case of machinery, both depreciation and opportunity cost can be attributed. In this study, total cost is defined as the sum of farm operating expenses (actual and imputed) and depreciation allowances. The measures of total cost and cost shares are constructed, with necessary modifications, from published and unpublished data from Statistics Canada and Agriculture Canada. The nature of modificiations and imputations are clarified below in the discussion of the cost of each input.

Cost of Land

Because of available data on land values and costs, this study takes land to also include buildings. The annual opportunity cost of land is estimated to be 5 percent of the nominal capital value of land and buildings. The choice of 5 percent as the fixed rate of interest which is used in the opportunity cost calculations over the entire period is

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[1]The issues are discussed by Brown (1978) and Statistics Canada (*Farm Net Income*) and Agriculture Canada.

somewhat arbitrary. In applying a 5 percent rate (which is arguably close to an appropriate real rate of interest) to annual nominal values over time, one generates a series of opportunity costs which clearly rise over time but in which inflationary impacts are not double-counted. The sum of the opportunity cost of land plus real estate taxes falling on land and repairs and depreciation on farm buildings, is taken to be the total cost of the services provided annually by land. These data are obtained from *Census of Canada, Agriculture (96-800)*, *Quarterly Bulletin of Agricultural Statistics (21-003)*, and *Farm Net Income (21-202)*.

Cost of Labour

In Canadian agriculture, hired labour does not constitute the major proportion of all farm labour though hired labour is increasing in importance as is indicated by the increase in the proportional share (in terms of persons employed) of hired labour from 16% to around 30% between 1961 and 1978. *Farm Net Income* reports only wages paid to hired labour. Imputation of costs for unpaid farm labour is necessary to recognize the dominant role and opportunity cost of this section of farm labour and to obtain a realistic cost share estimate. Cost imputations were made using the same wage rates as for hired labour for farm owner operators and using 70% of this wage for family workers. The use of a lower wage rate for family workers is based on the assumption that the marginal productivity of these workers

is lower than that of hired labour or owner operators.[2] Two concepts of quantity of labour--persons employed and manhours--are used in this study. Since manhours data are regarded as a better index of quantity of labour (Brown, 1978), most of our estimates are obtained using this concept. Manhours were multiplied by the appropriate hourly wage rate without board to obtain the cost of labour. Data sources used were: *The Labour Force (71-001); Labour Force, Annual Averages(71-529); Farm Net Income(21-202); and Farm Wages in Canada (21-002).* The manhours data relating to the three classes of farm labour for Canada and Western Canada were provided by Statistics Canada.

Cost of Machinery

The cost of machinery reported in *Farm Net Income* includes depreciation, expenditures on petroleum and diesel oil, machine repairs, and other expenses such as tires, antifreeze, and licenses. Since one of the specific objectives of this study is to treat energy separately from other farm inputs, the *Farm Net Income* specification is modified by exclusion of petroleum and diesel oil expenses which are added to electricity expenses to give the total cost of energy. The annual machinery cost is defined as the sum of depreciation, repairs, and other expenses plus 5% of the nominal capital value of all farm machinery. The latter

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[2] See Brown (1978: 58-59) for a discussion of the assertion that the productivity of family labour should be regarded as lower than that of hired labour.

subcomponent is assumed as a measure of the opportunity cost of machinery and corresponds to the 5% imputed opportunity cost of land. The relevant data are from *Farm Net Income* and the Agriculture Canada publication, *Selected Agricultural Statistics*.

Cost of Fertilizer

Fertilizer costs are defined as the sum of expenses on fertilizer and lime. Expenditures on fertilizer and lime as given in *Farm Net Income* are used without any modification in this study.

Cost of Energy

Energy cost is defined as the sum of expenditures on petroleum products and electricity. A similar definition has been used by Furniss (1978) in his study on energy use in Canadian agriculture and by Brown (1978). Expenditure on energy as defined above is compiled from various issues of *Farm Net Income*.

Cost of 'Other' Inputs

The cost of 'other' inputs consists of expenditures on seeds and feeds. The input 'other' is not included in our five input model of factor substitution, but it is used in the study of productivity in Chapter 6.

B. The Construction of Divisia Indexes

For estimation of the derived demand equations obtained from the translog cost function, Divisia price indexes of farm inputs are needed (see Chapter 6 for further justification). Divisia quantity indexes of farm output as a whole and of crops and livestock separately are also needed for model extensions involving non-homotheticity and joint output. The use of Divisia indexes was briefly explained in Chapter 3 and is elaborated further here.

The Conventional Laspeyres Index Approach

Statistics Canada indexes of farm input prices as given in *Farm Input Price Index (62-004)* are constructed using the Laspeyres formula:

$$P(t) = \frac{\Sigma[p(t)\ q(0)]}{\Sigma[p(0)\ q(0)]} \tag{4.1}$$

where P(t) is the index for the current period, p(t) and p(0) are the prices for the current and base periods, respectively, and Q(0) refers to physical quantity in the base period. The index given by (4.1) is a price index and can be written as:

$$P(t) = \frac{\Sigma[p(t)\ /\ p(0)]\ q(0)\ p(0)}{\Sigma[p(0)\ q(0)]} \tag{4.2}$$

The construction of price indexes such as (4.2) requires

both current and base period prices but only base period quantities.

It can be seen from both (4.1) and (4.2) that the Laspeyres index compares the current value of the base period quantities with the base period value of the base period quantities. It does not, therefore, take note of the way in which different subcomponents change in relative importance as a result of substitution. This causes bias in the estimated index when the relative importance of the subcomponents change over time as they have done in Canadian agriculture. In its key publication on farm input prices, *Farm Input Price Index*, Statistics Canada (1980: 6) recognizes the shortcoming of the Laspeyres index by saying:

> The FPI are suitable for use wherever a measure of movement of farm input prices is needed; from price monitoring through analytical studies, econometric models, cost escalating for stabilization programs, for deflating or inflating current dollar farm expenditures. Precaution should, however, be exercised when using the indexes. Since the indexes assume a constant "basket" of goods, they should not be interpreted as a measure of production cost movement because of substitution effects and changes in productivity which might have taken place since 1971.

Despite the limitations of the Laspeyres index, Statistics Canada continues to use this for input and output indexes. In this study, an alternative set of indexes based on the Divisia indexing method, which is not constrained by the restrictive assumptions of the Laspeyres method, is provided.

The Divisia Index

The Divisia index in its usual form is stated in continuous terms. To construct price and quantity indexes using yearly data, the following discrete approximation to the Divisia index given by Tornqvist (1936) is used:

$$\log P_t - \log P_{t-1} = \Sigma\, \bar{w}_{it}(\log p_{it} - \log p_{i,t-1}) \tag{4.3}$$

$$\log Q_t - \log Q_{t-1} = \Sigma\, \bar{w}_{it}(\log q_{it} - \log q_{i,t-1}) \tag{4.4}$$

where P and Q denote price and quantity and i refers to output or input subcomponents. The changing importance of the subcomponents is embodied in the weights $\bar{w}(it)$ which are the averages of the relative shares in any two adjacent periods. Three formulas for averaging--arithmetic, geometric, and combined--can be used for $\bar{w}(it)$.[3] Since the difference in the indexes obtained by using these different weights is usually very small and since it is a general practice to use arithmetic averages, this weight is used in our calculations.

The price indexes for the various input categories were constructed, as outlined previously, using the following subcomponents: land--both improved and unimproved; labour--hired, unpaid family, and farm operators;

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[3]See J. P. Chenier, ed., *Time Series Processor*, (Edmonton: University of Alberta, 1978).

machinery--tractors, combines and ploughs; fertilizer--mixtures and materials; and energy--petroleum products and electricity. Data sources include, in addition to those cited above, *Farm Implements and Equipment Sales (63-203)*, *Fertilizer Trade (46-207)*, and *Refined Petroleum Products (42-208)*. Data sources for output and the composition of output indexes are given in Chapter 6.

C. Cost Shares and Divisia Input Price Indexes

The shares of the various inputs in total cost (actual and imputed) are reported for Canada and Western Canada, respectively, in Tables 4.1 and 4.2. It can be seen from these tables that the share of labour steadily declined during the period covered by this study. Despite sharp increases in labour compensation, its share in total cost fell, partly because of absolute and heavy falls in the quantity of labour used prior to 1973. In Canadian agriculture, this input constituted 52.3% of total cost in 1961 while, in 1978, its share had fallen to 36.9%. A similar trend was observed in Western Canada, but the magnitude of the fall in labour's share was less (from 46.7% of total cost in 1961 to 38.5% in 1978).

The imputed share of land in total cost showed a slight though unsystematic increase from 1961 to 1978 at both the national and regional levels. Although the price of land showed the largest increase, the increase in the quantity of land, as expected, was quite moderate. As a result, this

Table 4.1: Cost Shares of Farm Inputs for Canada, 1961 to 1978.

Year	Land	Labour	Machinery	Fertilizer	Energy
1961	.2073	.5228	.1731	.0240	.0727
1962	.2254	.4964	.1814	.0257	.0710
1963	.2317	.4826	.1867	.0289	.0700
1964	.2425	.4623	.1924	.0335	.0692
1965	.2524	.4359	.2043	.0372	.0700
1966	.2648	.4144	.2103	.0421	.0683
1967	.2775	.4110	.2022	.0439	.0652
1968	.2890	.3920	.2058	.0471	.0661
1969	.2916	.4007	.2073	.0341	.0662
1970	.2849	.4034	.2143	.0312	.0692
1971	.2449	.4303	.2105	.0355	.0786
1972	.2541	.4120	.2165	.0366	.0787
1973	.2613	.4071	.2156	.0418	.0757
1974	.2673	.3953	.2195	.0476	.0725
1975	.2628	.3973	.2203	.0577	.0617
1976	.2875	.3755	.2241	.0505	.0624
1977	.2722	.3785	.2300	.0509	.0682
1978	.2643	.3695	.2450	.0527	.0683

Table 4.2: Cost Shares of Farm Inputs for Western Canada, 1961 to 1978.

Year	Land	Labour	Machinery	Fertilizer	Energy
1961	.2106	.4672	.2194	.0115	.0913
1962	.2182	.4606	.2216	.0127	.0873
1963	.2292	.4487	.2228	.0158	.0835
1964	.2439	.4234	.2282	.0216	.0827
1965	.2598	.3908	.2426	.0241	.0827
1966	.2726	.3775	.2487	.0313	.0799
1967	.2835	.3717	.2332	.0357	.0759
1968	.3013	.3369	.2419	.0458	.0792
1969	.2819	.3795	.2283	.0224	.0778
1970	.2883	.3614	.2501	.0162	.0839
1971	.2504	.3993	.2337	.0269	.0896
1972	.2475	.3874	.2503	.0272	.0875
1973	.2555	.3733	.2514	.0329	.0868
1974	.2334	.3982	.2317	.0447	.0920
1975	.2468	.3644	.2656	.0560	.0723
1976	.2736	.3665	.2491	.0422	.0685
1977	.2372	.3922	.2512	.0439	.0749
1978	.2291	.3850	.2674	.0450	.0735

factor's share in total cost did not rise that significantly.

The cost shares of machinery and fertilizer both rose during this period. In Canada, the share of machinery rose from 17.3% in 1961 to 24.5% in 1978. In Western Canada, the corresponding increase was from 21.9% to 26.7%. These figures indicate continuation of increased mechanisation of Canadian agriculture from 1961 to 1978. The share of fertilizer rose from 2.4% in Canada in 1961 to 5.3% in 1978 while in Western Canada, the share of this input rose from 1.1% to 4.5%. Simultaneous increases in the shares of machinery and fertilizer suggest the presence of both labour and land augmenting technical change in Canadian and Western Canadian agriculture.

The cost share of energy remained nearly unchanged over the period considered, fluctuating between 6.8% and 7.8% in Canada and 7.3% and 9.1% in Western Canada. The main reason why the share of energy did not rise despite increase in the quantity of energy consumed was the slow rise in the price of energy in relation to the prices of all farm inputs except machinery. By way of comparison, a nearly constant or slightly falling share of energy was found in several studies on U.S. manufacturing industries.[4]

Estimates of Divisia price indexes of land, labour, machinery, fertilizer, and energy are presented in Tables 4.3 and 4.4. The price of land shows the largest increase.

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[4] See, for example, Berndt and Wood (1975).

This is followed by the prices of labour, fertilizer, energy, and machinery. These trends were quite similar in Canada and in Western Canada. The price trends can be divided into two distinct periods. Until 1972, agricultural input prices rose very slowly and sometimes unsystematically (as in the case of fertilizer) but since 1972, the increases in prices have been fast and regular.

D. Divisia Indexes of Farm Output

Divisia indexes of farm output for Canada and Western Canada are reported in Tables 4.5 and 4.6. In Canada, the index of crop production increased relative to the base year of 1971 from 0.487 in 1961 to 1.175 in 1978 while the index of livestock production rose from 0.819 to 1.033 between 1961 and 1978. In Western Canada, the index of crop output increased at a faster rate than in Canada, rising from 0.364 to 1.264. The index of livestock production rose from 0.856 to 1.038 between 1961 and 1978. The all output index for Western Canada rose from 0.477 in 1961 to 1.223 in 1978. The growth rate of output in Western Canada was found to be higher (3.27%) than in Canada as a whole (2.01%). More detailed discussion of these indexes, including their construction and possible biases, in the context of an analysis of productivity, is given in Chapter 6.

The indexes presented in Tables 4.1 to 4.6 provide the basis to conduct an integrated study of changing input use in Canadian agriculture. Empirical estimates based on these

[illegible]

Table 4.3: Divisia Price Indexes of Farm Inputs
for Canada, 1961 to 1978.

Year	Land	Labour	Machinery	Fertilizer	Energy
1961	.504	.624	.709	1.004	.856
1962	.577	.624	.742	.993	.855
1963	.618	.648	.771	1.031	.853
1964	.701	.678	.803	1.033	.857
1965	.721	.697	.831	1.035	.856
1966	.773	.757	.870	1.015	.868
1967	.948	.824	.899	1.044	.866
1968	1.046	.854	.925	1.062	.926
1969	1.072	.915	.948	.997	.953
1970	1.072	.757	.972	.966	.968
1971	1.000	1.000	1.000	1.000	1.000
1972	1.101	1.078	1.035	1.039	1.015
1973	1.289	1.205	1.074	1.165	1.079
1974	1.629	1.411	1.206	1.653	1.213
1975	2.010	1.732	1.421	2.051	1.418
1976	2.577	1.945	1.586	2.010	1.632
1977	2.484	2.145	1.623	2.011	1.804
1978	2.653	2.259	1.722	2.123	1.928

Table 4.4: Divisia Price Indexes of Farm Inputs for Western Canada, 1961 to 1978.

Year	Land	Labour	Machinery	Fertilizer	Energy
1961	.512	.619	.693	1.043	.892
1962	.534	.643	.728	.987	.888
1963	.587	.665	.757	1.003	.891
1964	.778	.665	.795	1.038	.897
1965	.896	.690	.823	1.024	.881
1966	.872	.743	.866	1.060	.879
1967	1.034	.850	.896	1.034	.897
1968	1.120	.892	.922	1.077	.945
1969	1.062	.952	.953	1.089	.963
1970	1.046	.952	.978	.999	.976
1971	1.000	1.000	1.000	1.000	1.000
1972	1.039	1.088	1.028	1.068	1.023
1973	1.123	1.207	1.051	1.138	1.076
1974	1.484	1.455	1.116	1.261	1.173
1975	1.823	1.754	1.385	1.806	1.394
1976	2.228	2.040	1.505	2.203	1.626
1977	2.330	2.437	1.612	2.197	1.780
1978	2.629	2.568	1.804	2.200	1.891

Table 4.5: Divisia Indexes of Agricultural Outputs for Canada, 1961 to 1978.

Year	Crop	Livestock	All Output
1961	.487	.819	.619
1962	.745	.823	.779
1963	.861	.848	.860
1964	.751	.893	.809
1965	.832	.922	.871
1966	.992	.921	.969
1967	.796	.940	.861
1968	.874	.953	.910
1969	.928	.951	.938
1970	.851	.988	.915
1971	1.000	1.000	1.000
1972	.901	1.010	.948
1973	.947	.995	.972
1974	.826	1.012	.900
1975	.857	1.036	.987
1976	1.013	1.038	1.015
1977	1.069	1.042	1.044
1978	1.175	1.033	1.086

Table 4.6: Divisia Indexes of Agricultural Outputs Western Canada, 1961 to 1978.

Year	Crop	Livestock	All Output
1961	.364	.856	.477
1962	.681	.812	.723
1963	.826	.806	.836
1964	.679	.874	.733
1965	.810	.907	.846
1966	.964	.899	.967
1967	.713	.922	.774
1968	.842	.940	.879
1969	.770	.893	.809
1970	.803	.941	.842
1971	1.000	1.000	1.000
1972	.902	1.011	.934
1973	.947	1.004	.964
1974	.807	.997	.854
1975	.981	.989	.997
1976	1.114	1.019	1.110
1977	1.141	1.053	1.138
1978	1.264	1.038	1.223

data and using different specifications of the translog cost function are presented in Chapter 5.

V. FACTOR SUBSTITUTION AND TECHNICAL CHANGE IN CANADIAN AND WESTERN CANADIAN AGRICULTURE

In this chapter, the estimated coefficients of the derived demand functions for farm inputs in both Canada and Western Canada are presented. The estimates are based on the translog cost function. From these, quantitative estimates of factor substitution, factor demand, and the nature of technical change are derived. A test of the widely used value added specification is also presented.

Rather than providing only one set of estimates, several modifications of the translog function are used to provide a profile. These modifications involve: (a) a homothetic structure which includes time as an argument to serve as a proxy for technical change; (b) a homothetic joint output model with technical change in which output is disaggregated into crops and livestock; (c) a nonhomothetic structure which allows a scale factor to influence factor substitution; and (d) a nonhomothetic model which also incorporates technical change.

A. Derived Input Demand Functions

The derived demand functions corresponding to the single and joint output translog functions were stated in Chapter 3. To recapitulate the main estimating equations, the single output derived demand functions from Chapter 3 are given by:

$$S_i = a_i + \sum_j^n \gamma_{ij} \ln P_j + b_{Yi} \ln Y + \phi_{tP_i} t \qquad (3.5)$$

where S(i) is the share of i-th input in total cost.
The joint output homothetic derived demand equations from Chapter 3 can be written as:

$$S_i = b_i + \sum_j^m w_{ij} \ln P_j + \sum_j^n f_{ij} \ln Y_j + \phi_{tP_i} t \qquad (3.8)$$

where S(i) is the share of the i-th input in total cost.
The set of equations (3.5), which is stated in general terms, is used to study three production structures as mentioned above. The joint output derived demand equations, given by (3.8), are used to study only a homothetic structure with augmented technical change. The w(ij) coefficients in (3.8) correspond to the gamma coefficients in the single output derived demand equations (3.5). The restrictions which are placed on (3.5) and (3.8) and the

method of econometric estimation were discussed in Chapter 3.

The estimates of the derived demand functions allow assessment of the relevance of the translog function formulation relative to the Cobb-Douglas formulation. It might be recalled that if all input price coefficients are set equal to zero, the translog function collapses to the Cobb-Douglas function. If the estimated coefficients of input prices in the translog formulation are statistically significant, the translog function is clearly the preferred alternative.

B. Estimates for Canada

Homothetic Single Output Model With Technical Change

The estimated coefficients of the derived demand functions for the homothetic single output model which incorporates technical change are presented in Table 5.1.[1] Of the fourteen estimated coefficients of input prices,[2] twelve are statistically significant. The results imply that the use of the translog function is justified and preferred to the Cobb-Douglas specification. The standard error of the estimate (hereafter, SEE) corresponding to each share

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[1]Preliminary estimates of the key indicators of factor substitution, factor demand, and the nature of technical change in Canadian agriculture using a homothetic single output translog cost function based on persons employed labour data and no imputation of opportunity cost to machinery were presented in Islam and Veeman (1980).
[2]The fifteenth coefficient is obtained by using the homogeneity restriction. Hence, its t-value is not reported. The same procedure was followed by Binswanger (1974).

equation appears satisfactory. The R^2 estimates range between 0.66 and 0.90. Since the energy equation is deleted from estimation, no R^2 value is reported for this equation although it could be calculated indirectly. The smallness of the SEE confirm the goodness of fit indicated by the R^2 values. The Durbin-Watson statistics all fall within the indeterminate region.[3]

The estimated coefficients of input prices (the gamma coefficients), given in Table 5.1, do not have any clear economic meaning. These estimates are converted into Allen partial elasticities of substitution (AES) and own and cross price elasticities of demand (ED) and are reported in Table 5.2. The AES between any two inputs has important implications. It measures the relative ease with which one input substitutes for (or complements) another input in the production process. The values of AES were obtained from the estimated values of the coefficients of input prices and the cost shares of the relevant inputs using the following relations which were stated in Chapter 3:

$$\sigma_{ij} = \frac{\gamma_{ij} + S_i S_j}{S_i S_j}$$

$$\sigma_{ii} = \frac{\gamma_{ii} + S_i^2 - S_i}{S_i^2} \qquad (3.11)$$

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[3]This implies that while the hypothesis that there is no autocorrelation cannot be rejected, it is not accepted either.

Table 5.1: Estimates of Derived Input Demand Functions,[1] Homothetic Single Output Model With Technical Change, Canadian Agriculture

Equation	Land	Labour	Machinery	Fertilizer	Energy	Time	Intercept	R^2	SEE	D-W
Land	.1667**	-.1041**	-.0090	-.0228**	-.0246**	-.2324**	.2483	.8997	.071	1.60
	(14.60)	(-5.63)	(-1.08)	(-2.96)	(-2.52)	(-4.39)	(99.38)			
Labour		.1457**	-.0572**	-.0242	.0399**	-.6254**	.4239	.8842	.014	0.89
		(3.76)	(-3.87)	(-1.61)	(6.30)	(-6.81)	(88.48)			
Machinery			.0030**	.0208**	.0153**	.5416**	.2127	.8990	.005	0.95
			(2.95)	(3.04)	(3.66)	(10.08)	(113.03)			
Fertilizer				.0264**	-.0282**	.3152**	.0378	.6600	.005	1.13
				(5.80)	(-7.52)	(6.41)	(18.14)			
Energy					-.0024	.0010	.0773			

[1]The estimates were obtained using the symmetry restrictions and the restriction that the sum of the gamma coefficients is equal to zero for all i,j. The estimated coefficients of energy and of time in the energy equation were also obtained using the homogeneity restriction. The asymptotic t-values are given in parentheses. The significance of estimated coefficients at 1% and 5% levels is denoted by two and one asterisks, respectively.

where sigma(ij) denotes the AES between factors i and j.

As Table 5.2 indicates, substitutability relationships were found for the following pairs of inputs: land-labour; land-machinery; labour-machinery; labour-energy; machinery-fertilizer; and machinery-energy. Of these, the indicated substitution relationship between machinery and energy appears to be debatable on *a priori* grounds.[4] Machinery-energy substitutability in agriculture would imply that higher priced energy was associated with an increase and not, as *a priori* reasoning might suggest, a decrease in capital formation in the form of machinery. Prior to 1973, Canadian agriculture was operating in a cheap energy era. Even in the mid-1970s, the rise in energy prices does not appear to have significantly dampened the use of machinery, probably because the substantial and continued rise in the price of labour relative to capital (and indeed, relative to energy) has continued to encourage the tendency for capital-labour substitution and mechanical innovation and adoption. The estimated relationship between all the other input pairs appears sensible. The relationship between labour and machinery is consistent with the decline in the amount of labour and the increased mechanization of Canadian agriculture. Substitutability between land and labour and between land and machinery are also sensible results which are compatible with the observed decrease in the use of

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[4]In studies of manufacturing sectors, capital-energy relationships are not fully resolved (Berndt and White, 1979).

Table 5.2: Estimates of Partial Elasticities of Substitution, Homothetic Single Output Model With Technical Change, Canadian Agriculture

	Land	Labour	Machinery	Fertilizer	Energy
Land	$-.0257^{++}$	$.0501^{++}$	.8342	-1.1923^{++}	$-.2265^{++}$
Labour		$-.5520^{++}$	$.3500^{++}$	-.4353	2.3000^{++}
Machinery			-3.7204^{++}	3.4904^{++}	2.0528^{++}
Fertilizer				-12.5000^{++}	-9.1293^{++}
Energy					-14.0100

$^{++}$, $^{+}$ denote the values of AES obtained from coefficients of input prices significant at 1% and 5% level, respectively.

Table 5.3: Estimates of Own and Cross Price Elasticities of Demand, Homothetic Single Output Model With Technical Change, Canadian Agriculture

	Land	Labour	Machinery	Fertilizer	Energy
Land	-.0066	.0211	.1741	.0477	-.0158
Labour	.0130	-.2193	.0731	-.0174	.1642
Machinery	.2169	.1475	-.7768	.1396	.1428
Fertilizer	-.3099	-1.5681	.7288	-.5012	.6354
Energy	-.0589	.9947	.5220	-.3612	-.9751

labour, moderate increase in the acreage of land, and significant increase in the use of machinery. All these pairs were also found to be substitutes by Binswanger(1973) and Lopez (1980) in their studies of U.S. and Canadian agriculture.

Four pairs of inputs displayed complementarity relationships. Complementarity between energy and fertilizer is plausible but that between fertilizer and land appears counterintuitive. Labour-fertilizer complementarity appears to be a common feature of both Canadian and U.S. agriculture--a similar result was obtained by Binswanger (1973). This result cannot be compared with those of Lopez (1980) who did not treat fertilizer separately (and who found all the inputs considered to be substitutes).

Estimates of own and cross price elasticities of demand (ED) are important indicators of responsiveness of demand for a particular input to changes in its own price and to prices of other inputs. These estimates, reported in Table 5.3, were obtained using the following relationships:

$$(ED)_{ij} = S_j \sigma_{ij}$$

$$(ED)_{ii} = S_i \sigma_{ii} \tag{3.12}$$

where sigma(ij) is the AES between factors i and j and S(i) is the share of the i-th input in total cost. Unlike the estimates of AES, the estimates of ED are not symmetric unless, by chance, S(i)=S(j).

It can be seen from Table 5.3 that the lowest own price ED applies to land. A similar result was obtained for U.S. agriculture by Binswanger (1973). Of the other own price elasticities, the ED of energy is the highest followed by that of machinery, fertilizer, labour, and land. Among the cross price elasticities, the highest positive value is between energy and labour and the largest negative value is between fertilizer and labour.

An attempt to incorporate technical change in the model was made by including time directly as an argument in the cost function. Some inferences as to the nature of technical change can be made by examining the estimated coefficients of this variable from the share equations given in Table 5.1. All four of the estimated coefficients relating to time are significant. These coefficients are negative for land and labour (implying that technical change has been both land- and labour-saving) and positive for machinery and fertilizer (implying machinery- and fertilizer-using technological change). The coefficient of time in the energy equation, obtained by using the restriction that the sum of the coefficients of time is zero, is positive but very small. This indicates a weak energy-using bias. These general results are consistent with *a priori* reasoning and with the observation that land and labour have registered the largest price increases of these five inputs during the 1961 to 1978 period. The positive time coefficients in both the machinery and fertilizer equations imply that technical

change in Canadian agriculture has been both labour- and land-augmenting rather than being only labour-augmenting as Furtan and Lee (1977) argued was the case for the Saskatchewan wheat economy.

The translog function reduces to the Cobb-Douglas (CD) function when the gamma coefficients are all set equal to zero. The CD estimates of own and cross price elasticities are reported in Table 5.4. There are no estimates of AES since, by definition, these are equal to unity for the CD specification.

It can be seen from Table 5.4 that the CD estimates of own price ED of land and fertilizer are appreciably higher than those obtained using the translog function. The cross price ED indicate the more restrictive features of the CD specification. First, since the CD function restricts the value of AES to +1, there is no possibility of complementarity relations between inputs. Second, because the elasticity of substitution is the same (equal to one) for all pairs of inputs, all cross price ED of the inputs with respect to any given input (column values) are the same. The restricted ES and the biases in the ED for inputs suggest that the use of the translog function should be preferred over the Cobb-Douglas specification.

Homothetic Joint Output Model With Technical Change

The estimated coefficients of the derived demand functions corresponding to the joint output model which uses two distinct output classifications of crops and livestock

Table 5.4: Cobb-Douglas Estimates of Own and Cross Price Elasticities of Input Demand, Canadian Agriculture

	Land	Labour	Machinery	Fertilizer	Energy
Land	-.7400	.4215	.2088	.0400	.0696
Labour	.2600	-.5785	.2088	.0400	.0696
Machinery	.2600	.4215	-.7912	.0400	.0696
Fertilizer	.2600	.4215	.2088	-.9600	.0696
Energy	.2600	.4215	.2088	.0400	-.9304

are reported in Table 5.5. Save the joint-output feature, the model is otherwise similar to the previous single output model and also incorporates time as a proxy for technical change. Twelve of the fourteen estimated coefficients of input prices are significant. The values of R^2 range from 0.74 to 0.94. The values of SEE are again found to be very low. The D-W statistics value range from 0.97 to 1.72.

The estimated values of AES and ED are presented in Tables 5.6 and 5.7. Scrutiny of the AES values shows that of the ten pairs of farm inputs, four are complements while the rest are substitutes. The nature of the substitutability and complementarity relationships between various inputs are very similar in the two models (homothetic single and homothetic joint) though the magnitudes differ.

The estimates of own and cross price elasticities (ED), given in Table 5.7, show some differences from the single output model. The joint output model gave higher estimates of ED for land and labour, and lower estimate for machinery, fertilizer, and energy.

The nature of technical change may again be inferred from the coefficient on time in the derived demand equations. As in the single output model, negative coefficients on time in the land and labour equations imply that technical change has been land- and labour-saving. The time coefficients in both the machinery and fertilizer share equations are positive suggesting the presence of both land- and labour-augmenting technical change. The time coefficient

Table 5.5: Estimates of Derived Demand Functions, Homothetic Joint Output Model With Technical Change, Canadian Agriculture[1]

Equation	Land	Labour	Machinery	Fertilizer	Energy	Crop[2]	Livestock[2]	Time	Intercept
Land	.1626**	-.0943**	-.0160*	-.0216*	-.0306**	.0294**	.0732	-.4228**	.2531
	(13.13)	(-5.56)	(-2.09)	(-2.86)	(-6.67)	(2.92)	(1.22)	(-4.52)	(81.30)
Labour		.1091**	-.0423**	-.0236	.0512**	-.0731**	-.1778	-.1091	.4114
		(3.57)	(3.29)	(-1.96)	(8.02)	(-4.46)	(-1.85)	(-0.68)	(31.88)
Machinery			.0368**	.0202**	.0011	.0257**	.0246	.4134**	.2169
			(3.30)	(3.09)	(0.03)	(4.03)	(0.61)	(5.15)	(117.02)
Fertilizer				.0340**	-.0290**	.0208**	.0281	.2124**	.0405
				(6.15)	(-7.23)	(3.07)	(0.73)	(3.25)	(19.77)
Energy					.0063	-.0028	.0519	-.0939	.0781

[1] Asymptotic t-values in parentheses.
[2] Estimated coefficients on (the natural logarithm of) crop and livestock output, respectively.
The coefficients in the energy equation are obtained by using the relevant constraints outline in (3.6).

Goodness of Fit and D-W Statistics

Share equation	R^2	SEE	D-W
Land	.9296	.006	1.72
Labour	.9406	.010	0.99
Machinery	.9447	.004	0.97
Fertilizer	.7472	.004	1.32

Table 5.6: Estimates of Partial Elasticities of Substitution, Homothetic Joint Output Model With Technical Change, Canadian Agriculture

	Land	Labour	Machinery	Fertilizer	Energy
Land	$-.4408^{++}$	$.1395^{++}$	$.7053^{++}$	-1.0769^{++}	$-.6885^{++}$
Labour		$-.7582^{++}$	$.5194^{++}$	$-.3998^{++}$	2.7453^{++}
Machinery			-2.9451^{++}	3.4186^{++}	1.0757
Fertilizer				-4.7500^{++}	-9.4167^{++}
Energy					-12.0673

Table 5.7: Estimates of Own and Cross Price Elasticities of Demand, Homothetic Joint Output Model With Technical Change, Canadian Agriculture.

	Land	Labour	Machinery	Fertilizer	Energy
Land	-.1146	.0588	.1473	-.0431	-.0479
Labour	.0362	-.3196	.1084	-.0160	.1910
Machinery	.1834	.2189	-.6149	.1422	.0749
Fertilizer	-.2800	-.1685	.7138	-.1976	-.6554
Energy	-.1796	1.1571	.2246	.3914	-.8399

in the energy equation is found to be negative but small. This implies a mild energy-saving bias.

Nonhomothetic Single Output Model Without Technical Change

The estimates presented above are based on a homothetic structure which does not take into account possible scale effects. As mentioned in Chapter 3, a nonhomothetic structure can be adopted by dropping the restriction that each coefficient of output is equal to zero. When this is done, input demand becomes a function of both input prices and the level of output rather than only input prices as in the homothetic case.

Since the study by Lopez (1980) using the generalized Leontief cost function for Canadian agriculture suggested that estimates of the impact of technical change may be sensitive to the specification of a homotheticity restriction, this study included two nonhomotheticity model variants. In the first, technical change was not expressly considered. In the second, technical change was considered, as before, by inclusion of time as a variable in the share equations. In each variant, the non-homotheticity extension was applied only to the single output model.

The estimated coefficients of the derived demand equations which do not include time as an argument are presented in Table 5.8. Of the fourteen estimates of coefficients of input prices, eleven were found statistically significant. The values of R^2 for the four estimated equations range from 0.85 to 0.95. The estimated

Table 5.8: Estimates of Derived Input Demand Functions, Nonhomothetic Single Output Model Without Technical Change, Canadian Agriculture

	Land	Labour	Machinery	Fertilizer	Energy	Output	Intercept	R^2	SEE	D-W
Land	.1302** (9.46)	-.1427** (-8.31)	.0384** (6.74)	.0016 (0.23)	-.0275** (-6.28)	.0369* (2.18)	.2533 (76.52)	.8698	.081	1.53
Labour		.0845** (3.18)	.0091 (1.02)	.0057 (0.56)	.0529** (8.21)	-.1313** (-5.97)	.4177 (103.24)	.4514	.092	1.19
Machinery			-.0438** (-7.91)	-.0152** (-3.17)	.0115** (3.77)	.0534** (5.92)	.2131 (118.08)	.8931	.005	1.68
Fertilizer				.0156** (5.26)	-.0338** (-10.06)	.0517** (4.90)	.0389 (22.16)	.8538	.004	1.99
Energy					-.0038	-.0107	.0870			

coefficients of the output variable show the strength of nonhomotheticity. These are all statistically significant. This result implies that inclusion of output in the derived demand functions for Canadian agriculture is relevant. Whether or not its inclusion significantly affects input relationships can be seen by examining the revised values of AES and ED in Table 5.9 and 5.10.

The estimates of AES from the nonhomothetic structure do differ from those estimates when the homotheticity constraint is invoked. Changes in the nature of the relationships between inputs occurred with land-fertilizer, labour-fertilizer, and land-labour pairs. The first two pairs were found to have a complementarity relationship in the homothetic single output model, but are now observed to be substitutes; the estimated coefficients on which these calculations are based are, however, insignificant. The last pair which displayed substitutability in the single output homothetic model now show a complementarity relationship. The estimates of ED are given in Table 5.10. The highest absolute value applies to machinery, followed by energy, fertilizer, labour, and land.

Nonhomothetic Single Output Model With Technical Change

The estimates of the derived demand functions of the translog model which incorporates both nonhomotheticity and augmented technical change are reported in Table 5.11. Of the fourteen estimated price coefficients of input prices, all but two (machinery in the land equation and fertilizer

Table 5.9: Estimates of Partial Elasticities of Substitution, Nonhomothetic Single Output Model Without Technical Change, Canadian Agriculture

	Land	Labour	Machinery	Fertilizer	Energy
Land	$-.9201^{++}$	$-.3021^{++}$	1.7073^{++}	1.1538	$-.5249^{++}$
Labour		-.8964	1.1034	1.3381	2.4760^{++}
Machinery			-4.7936^{++}	$-.8199^{++}$	1.7931^{++}
Fertilizer				-14.2500^{++}	-11.1408^{++}
Energy					-14.3050

Table 5.10: Estimates of Own and Cross Price Elasticities of Demand Nonhomethetic Single Output Model Without Technical Change, Canadian Agriculture

	Land	Labour	Machinery	Fertilizer	Energy
Land	-.2349	-.1273	.3565	.0461	-.0361
Labour	.0785	-.3765	.2304	.0535	.1723
Machinery	.4438	.4651	-1.0066	-.0327	.0748
Fertilizer	.2999	.5640	.1712	-.5700	-.7754
Energy	-.1351	1.0436	.2246	-.4456	-.9956

Table 5.11: Estimates of Derived Input Demand Functions, Nonhomothetic Single Output Model With Technical Change, Canadian Agriculture

Equation	Land	Labour	Machinery	Fertilizer	Energy	Time	Output	Intercept	R^2	SEE	D-W
Land	.1625** (15.54)	-.0994** (-6.77)	-.0096 (-1.27)	-.0230** (-3.36)	-.0304** (-7.43)	-.3428** (-5.83)	.0579** (3.62)	.2525 (106.22)	.9307	.006	1.68
Labour		.1102** (3.82)	-.0394** (-3.09)	-.0149 (-1.23)	.0435** (6.97)	-.2626* (-2.61)	-.1371** (-4.97)	.4137 (102.01)	.9383	.010	1.06
Machinery			.0203* (1.99)	.0149* (2.28)	.0137** (3.17)	.4153** (6.73)	.0415** (3.55)	.2159 (124.06)	.9304	.004	1.31
Fertilizer				.0540** (6.09)	-.0310** (-8.13)	.1934** (3.83)	.0463** (3.94)	.0407 (22.16)	.7735	.004	1.32
Energy					.0042	.0033	-.0086	.0772			

in the labour equation) are statistically significant. The values of R^2 are quite high and range between 0.77 and 0.94.

The calculated AES are presented in Table 5.12. The relationships are quite similar to those observed in the homothetic single output model. An important exception is the labour-fertilizer relationship which appeared to be one of complementarity in the homothetic case and now appears to be a substitute relationship. However, this latter relationship is derived from a statistically nonsignificant coefficient on the relevant input prices. The estimates of ED, given in Table 5.13, show that the value of ED for energy is the highest followed by those for machinery, labour, and land. The value of ED of fertilizer was observed to be positive.[5]

The coefficients on the explanatory variable, output, which reflects the nonhomothetic structure, are found to be significantly different from zero in each equation. The estimated coefficients on the time variable are also significant in each of the four estimated share equations. The signs on the time coefficients in the land and labour equations are all negative (implying land- and labour-saving technical change) while those in the machinery, fertilizer, and energy equations are all positive. These results are similar to those for the homothetic structure although the magnitudes of the estimated coefficients differ. The results

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[5] The occasional empirical estimate of a positive value of own price ED of a farm input is not uncommon. See Baanante and Sidhu (1980), and Chotigeat (1978).

Table 5.12: Estimates of Partial Elasticities of Substitution, Nonhomothetic Single Output Model With Technical Change, Canadian Agriculture

	Land	Labour	Machinery	Fertilizer	Energy
Land	$-.4423^{++}$	$.0930^{++}$	$.8232^{+}$	-1.2115^{++}	$-.6799^{++}$
Labour		$.7522^{++}$	$.5523^{++}$	$.1162^{+}$	2.4827^{++}
Machinery			-3.3236^{+}	2.7840^{++}	1.9427^{++}
Fertilizer				7.7500^{++}	-10.1350^{++}
Energy					-12.4900

Table 5.13: Estimates of Own and Cross Price Elasticities of Demand Nonhomethetic Single Output Model With Technical Change, Canadian Agriculture

	Land	Labour	Machinery	Fertilizer	Energy
Land	-.1150	.0392	.1719	-.0504	-.0473
Labour	.0241	-.3170	.1153	.0046	.1728
Machinery	.2140	.2328	-.6940	.1114	.1352
Fertilizer	.3150	.0490	.5813	.3224	-.7054
Energy	-.1768	1.0464	.4216	-.4216	-.8693

regarding technical change differ from those obtained by Lopez (1980). Lopez applied a nonhomothetic generalized Leontief function (with a different input classification) to Canadian agriculture and found that three of the four estimated coefficients on time were insignificant. In contrast, the significance of the technical change variable in this study is in accord with the substantial evidence of the existence of (biased or factor-augmenting) technical change in Canadian agriculture.

C. Estimates for Western Canada

In this section, the empirical results of the preceding four model variations are reported for the Western Canadian agricultural sector.

Homothetic Single Output Model With Technical Change

Estimates of the coefficients of the derived demand functions based on a homothetic structure which incorporates technical change by the addition of a time variable are presented in Table 5.14. A slight decline in the level of significance of the coefficients on inputs and time and, except in one instance, a decline in the explanatory power of the estimated equations are apparent relative to the estimates for Canada (Table 5.1). Nonetheless, with respect to the signs, size, and significance of the coefficients as well as the R^2 values, the estimates for Western Canada are generally comparable with those for Canada.

Table 5.14: Estimates of Derived Input Demand Functions, Homothetic Single Output Model With Technical Change, Western Canadian Agriculture

Equation	Land	Labour	Machinery	Fertilizer	Energy	Time	Intercept	R^2	SEE	D-W
Land	.1566** (6.31)	-.1536** (-6.32)	.0011 (0.05)	.0111 (0.85)	-.0152* (-1.69)	.0074 (0.07)	.2456 (59.46)	.6188	.015	1.03
Labour		.1688** (4.09)	-.0886* (-2.42)	-.0055 (-0.21)	.0790** (4.57)	-.3523 (-2.03)	.3902 (91.52)	.8395	.013	1.94
Machinery			.0605 (1.44)	.0318 (1.31)	-.0048 (-0.25)	.5134* (2.99)	.2462 (68.80)	.7087	.007	2.90
Fertilizer				.0277* (1.76)	-.0751** (-5.79)	.1280 (1.10)	.0293 (11.84)	.7615	.006	1.67
Energy					.0161	-.2965	.0887			

As before, the estimated input price coefficients are converted into Allen partial elasticities of substitution (AES) and price elasticities of demand (ED). The estimates of AES, given in Table 5.15, show that except for the land-labour and fertilizer-energy input pairs which displayed complementarity, substitutability relationships prevailed for other pairs of farm inputs. Of the changes in estimates based on significant estimated values of input price coefficients from the similar model for Canada (homothetic single output), the most striking change is the tripling of the magnitude (in absolute value terms) of the fertilizer-energy AES. Except for the land-machinery pair, the values of AES for all other pairs of farm inputs were different from the Cobb-Douglas (CD) specification of unitary elasticity of substitution. The rejection of the CD specification is a common feature in the results on factor substitution in agriculture in Western Canada and Canada.

The estimated price elasticities of input demand (ED) are reported in Table 5.16. The absolute values of all the own price elasticities of demand were less than one implying relatively inelastic demand for farm inputs. The lowest value of own price ED was found for fertilizer in the Western Canadian case. The estimates for labour, machinery, and energy for Western Canada are slightly less elastic than in the case of Canada as a whole.

The coefficient on time in the derived demand equations in Table 5.14 gives an indication of land-using technical

Table 5.15: Estimates of Partial Elasticities of Substitution, Homothetic Single Output Model With Technical Change, Western Canadian Agriculture

	Land	Labour	Machinery	Fertilizer	Energy
Land	$-.5072^{++}$	$-.5406^{++}$	1.0180	2.4222	$.2649^{+}$
Labour		$-.4513^{++}$	$.0648^{+}$	.5459	3.4615^{++}
Machinery			-2.1074	5.2858	.7558
Fertilizer				-2.4400^{+}	-29.0400^{++}
Energy					-8.8369

Table 5.16: Estimates of Own and Cross Price Elasticities of Demand, Homothetic Single Output Model With Technical Change, Western Canadian Agriculture

	Land	Labour	Machinery	Fertilizer	Energy
Land	-.1285	-.2134	.2452	.0746	.0216
Labour	.1162	-.1775	.0156	.0168	.2824
Machinery	.2572	.0154	-.5076	.1628	.0616
Fertilizer	.6137	.2147	1.2733	-.0751	-2.3696
Energy	.0671	1.3614	.1379	-.8944	-.7211

change, but the coefficient is small and is not significant. The labour-saving bias is again apparent. The estimated coefficients on time are positive in the machinery and fertilizer share equations implying factor using technical change although only the coefficient on time in the machinery equation is significant at the five percent level. In contrast to the result for Canada (Table 5.1), the coefficient on time in the energy equation is now negative implying an energy-saving bias in input use in Western Canada.

Cobb-Douglas estimates of own and cross price elasticities of demand for Canadian agriculture were reported in Table 5.4. Similar estimates for Western Canada are presented in Table 5.17. The labour input shows the lowest elasticity of demand followed by that of land, machinery, energy, and fertilizer. A very similar ranking was also obtained for Canada. The CD ranking for Western Canada differs from that obtained by using the translog function. Since the use of the translog function has been empirically vindicated, the CD estimates, bound by the unitary elasticity of substitution restriction, are felt to be less reliable.

Homothetic Joint Output Model With Technical Change

The estimates of the joint output derived demand functions are reported in Table 5.18. Seven of the fourteen estimated coefficients of input prices were found to be significant. The values of R^2 range from 0.62 to 0.83.

Table 5.17: Cobb-Douglas Estimates of Own and Cross Price Elasticities of Input Demand, Western Canadian Agriculture

	Land	Labour	Machinery	Fertilizer	Energy
Land	-.7466	.3933	.2409	.0308	.0816
Labour	.2534	-.6067	.2409	.0308	.0816
Machinery	.2534	.3933	-.7591	.0308	.0816
Fertilizer	.2534	.3933	.2409	-.9692	.0816
Energy	.2534	.3933	.2409	.0308	-.9184

Table 5.18: Estimates of Derived Demand Functions, Homothetic Joint Output Model With Technical Change, Western Canadian Agriculture[1]

Equation	Land	Labour	Machinery	Fertilizer	Energy	Crop[2]	Livestock[2]	Time	Intercept
Land	.1583**	-.1603**	.0086*	.0184	-.0171*	-.0027	-.0522	.1052	.2436
	(6.39)	(-6.34)	(0.49)	(0.89)	(-2.05)	(-0.14)	(-0.51)	(0.53)	(35.20)
Labour		.1876	-.0662	-.0110	.0449	.0008	-.0293	-.3811	.3906
		(4.21)	(-1.75)	(-0.45)	(2.89)	(0.04)	(-0.28)	(-1.42)	(59.99)
Machinery			.0157**	.0271	.0147	.0136	.0631	.2838	.2470
			(0.37)	(1.18)	(0.85)	(1.22)	(1.08)	(1.29)	(63.42)
Fertilizer				.0410	-.0696**	.0001	.0290	.1153	.0299
				(2.16)	(-5.86)	(0.08)	(0.70)	(0.86)	(10.60)
Energy					.0221	-.0118	-.0106	-.1232	.0889

[1]Asymptotic t-values in parentheses.
[2]Estimated coefficients on (the natural logarithm of) crop and livestock output, respectively.

Goodness of Fit and D-W Statistics

Share equation	R^2	SEE	D-W
Land	.6277	.0051	1.01
Labour	.8283	.0142	1.82
Machinery	.7292	.0073	3.06
Fertilizer	.7680	.0062	1.59

Compared to the estimates of the joint output model for Canada, Western Canadian estimates appear weaker.

The estimates of AES are reported in Table 5.19. There are some changes in the magnitudes of AES, but the fundamental nature of relationships between various input pairs shows little change from the single output homothetic model.

The estimates of ED, reported in Table 5.20, show only one change compared to the estimates of the single output model. The highest own price elasticity is displayed by machinery, followed by that of energy, while in the preceding model, their ordering was reversed.

The evidence on technical change is quite similar from both these Western Canadian models. The coefficient on time in the land equation is positive but again is found to be insignificant. Labour-saving and machinery- and fertilizer-using biases are again observed, but the time coefficients in these equations all show a very low level of significance. The time coefficient in the energy equation, obtained indirectly, shows a small energy-saving bias. This is a plausible result and could arise due to a lower increase in the price of energy compared to increases in the prices of other farm inputs and because it may have been easier to control the use of this nondurable input through conservation and more efficient use.

Table 5.19: Estimates of Partial Elasticities of Substitution, Homothetic Joint Output Model With Technical Change, Western Canadian Agriculture

	Land	Labour	Machinery	Fertilizer	Energy
Land	$-.4812^{++}$	$-.6084^{++}$	1.1409	2.7692	$.1730^{++}$
Labour		$-.3303^{++}$	$.3013^{+}$	.0919	2.5548^{+}
Machinery			-2.8827	4.6524	1.7478
Fertilizer				$-.3750^{+}$	-26.6929^{++}
Energy					-7.9447

Table 5.20: Estimates of Own and Cross Price Elasticities of Demand, Homothetic Joint Output Model With Technical Change, Western Canadian Agriculture

	Land	Labour	Machinery	Fertilizer	Energy
Land	-.1219	-.2393	.2748	.1152	.0411
Labour	.1542	-.1299	.0726	.0028	.2085
Machinery	.2891	.1185	-.6944	.1433	.1426
Fertilizer	.5910	.0361	1.1207	-.0016	-2.1781
Energy	.0438	1.0048	.4210	-.8221	-.6483

Nonhomothetic Single Output Model Without Technical Change

The nonhomothetic form of the translog function was also applied to Western Canadian agriculture. As was the case for Canada, two nonhomothetic model versions were estimated, one without express consideration of technical change and the second incorporating time as a variable to account for technical change. In both instances, only the single output structure was used.

The estimates of derived input demand equations corresponding to the nonhomothetic structure without technical change are reported in Table 5.21. Two of the four estimated output coefficients are significantly different from zero. This implies some presence of nonhomotheticity, i.e., the level of output has some influence on the estimates of factor substitution. The extent of nonhomotheticity is not as strong in the case of Western Canada as it is in Canada for which all four output coefficients were found significant.

From the estimates of derived demand equations it can be seen that 12 of the 14 coefficients of input prices are statistically significant. This is a marked increase compared to the single output homothetic model for Western Canada in which 8 of the 14 estimated coefficients were found significant. The R^2 values range between 0.60 and 0.81.

The estimates of AES, presented in Table 5.22, show some changes relative to the single output homothetic

Table 5.21: Estimates of Derived Input Demand Functions, Nonhomothetic Single Output Model Without Technical Change, Western Canadian Agriculture

Equation	Land	Labour	Machinery	Fertilizer	Energy	Output	Intercept	R^2	SEE	D-W
Land	.1510** (6.10)	-.1758** (-8.27)	.0256* (1.97)	.0214* (2.07)	-.0202** (-2.68)	.0192 (0.99)	.2478 (52.48)	.6013	.016	0.91
Labour		.1234** (5.00)	.0004 (0.03)	.0248* (2.38)	.0272** (3.57)	-.0336 (-1.88)	.3919 (88.28)	.8106	.015	1.54
Machinery			-.0485** (-2.64)	-.0112 (-1.09)	.0348* (2.18)	.0381** (3.00)	.2441 (77.98)	.6319	.008	2.81
Fertilizer				.0223* (-1.77)	-.0563** (-5.11)	.0013 (0.13)	.0274 (11.12)	.7807	.006	1.78
Energy					.0165	-.0250	.0888			

Table 5.22: Estimates of Partial Elasticities of Substitution, Nonhomothetic Single Output Model Without Technical Change, Western Canadian Agriculture

	Land	Labour	Machinery	Fertilizer	Energy
Land	$-.5948^{++}$	$-.7646^{++}$	1.4193^{+}	3.7419^{++}	$-.0736^{++}$
Labour		$-.7448^{++}$	1.0042	3.0473^{++}	1.8475^{++}
Machinery			-3.9874^{++}	-.5595	2.7703^{++}
Fertilizer				-8.4444^{+}	-22.4010^{++}
Energy					-8.8069

Table 5.23: Estimates of Own and Cross Price Elasticities of Demand, Nonhomothetic Single Output Model Without Technical Change, Western Canadian Agriculture

	Land	Labour	Machinery	Fertilizer	Energy
Land	-.1507	-.3007	.3419	.1152	-.0051
Labour	-.1937	-.2929	.2410	.0938	.1507
Machinery	.3596	.3934	-.9606	-.0157	.2260
Fertilizer	.9482	1.1985	-.1227	-.2601	-1.8279
Energy	-.0186	.7266	.6674	-.6899	-.7186

estimates. Complementarity relationships hold for four input pairs rather than one as was observed in the homothetic case. Of these four pairs, three have statistically significant coefficients on input prices.

Own and cross price ED are reported in Table 5.23. The land input shows the lowest ED followed, in turn, by fertilizer, labour, energy, and machinery. All estimates of own price ED are less than one. The ranking of own price ED bears close similarity to that from each of the previous two models.

Nonhomothetic Single Output Model With Technical Change

In this section, the estimated coefficients of the derived demand functions which allow for nonhomotheticity and incorporate time as a proxy for technical change are reported. As explained above, this modification enables testing of whether (a) input relationships undergo significant changes, (b) provision of a technical change variable suppresses or absorbs nonhomotheticity, and (c) evidence of augmented technical change remains in the nonhomothetic structure.

The estimated coefficients of the derived demand functions for this model are presented in Table 5.24. Seven of the fourteen estimated coefficients of input prices are statistically significant. This is comparable to the significance of the coefficients of the first two models but is less than in the preceeding nonhomothetic model. The values of R^2 ranged between 0.62 and 0.83.

Table 5.24: Estimates of Derived Input Demand Functions, Nonhomothetic Single Output Model With Technical Change, Western Canadian Agriculture

Equation	Land	Labour	Machinery	Fertilizer	Energy	Time	Output	Intercept	R^2	SEE	D-W
Land	.1560** (6.12)	-.1578** (-6.25)	.0043 (0.22)	.0144 (1.11)	-.0170* (-2.00)	.0261 (0.20)	-.0006 (-0.02)	.2455 (52.37)	.6166	.015	1.03
Labour		.1943** (4.14)	-.0815* (-1.97)	-.0040 (-0.14)	.0490** (2.69)	-.4618* (-2.06)	.0045 (0.18)	.3900 (81.48)	.8329	.014	1.90
Machinery			.0411 (0.90)	.0230 (0.88)	.0130 (0.69)	.4496* (2.15)	.0015 (0.79)	.2469 (68.47)	.7140	.007	2.93
Fertilizer				.0146 (1.43)	-.0644* (-5.09)	.1178 (0.85)	-.0004 (-0.04)	.0294 (11.47)	.7580	.006	1.64
Energy					-.0310	-.1317	-.0050	.0882			

The estimates of the values of AES are reported in Table 5.25. These value show complementarity relationships for the input pairs of land-labour, land-energy and fertilizer-energy, and substitution relationship for the rest. These results show that there is no major change in general input relationships compared to the preceeding nonhomothetic model though there are changes in the magnitudes of the values of AES. The estimates of elasticities of demand (ED) are reported in Table 5.26. The demand for land is found to be most inelastic followed by that for labour, fertilizer, machinery, and energy.

The estimated coefficients of the derived demand equations in Table 5.24 show that two of the four coefficients on time are significant at the 5 percent level, that is, there is only weak evidence of technical change. The time coefficient in the land equation is positive but very small and insignificant. Labour-saving bias is again observed from the negative and significant coefficient on time in the labour equation. The time coefficients in both the fertilizer and machinery equations are found to be positive though the former is nonsignificant. There again appears to be a small energy saving bias indicated by the negative sign of the derived time coefficient in the energy equation.

The estimates of the derived input demand functions show another interesting result. The strength of nonhomotheticity, given by the coefficients on output in

Table 5.25: Estimates of Partial Elasticities of Substitution, Nonhomothetic Single Output Model With Technical Change, Western Canadian Agriculture

	Land	Labour	Machinery	Fertilizer	Energy
Land	$-.5171^{++}$	$-.5827^{++}$	1.0704	2.8391	-0.6500^{+}
Labour		-.2863	$.1398^{+}$	.6708	4.0841^{++}
Machinery			-2.4448^{++}	4.0998	1.6613^{++}
Fertilizer				-17.1100	-7.6796
Energy					-15.8059

Table 5.26: Estimates of Own and Cross Price Elasticities of Input Demand, Nonhomothetic Single Output Model With Technical Change, Western Canadian Agriculture

	Land	Labour	Machinery	Fertilizer	Energy
Land	-.1310	-.2298	.2578	.0874	-.0345
Labour	-.1491	-.1160	.0337	.0207	.3326
Machinery	.2712	.0550	-.5889	.1263	.1356
Fertilizer	.7194	.2638	.9876	-.5236	.6266
Energy	.0450	1.6062	.4002	.2365	-1.2898

Table 5.23, appears very weak. None of the coefficients on output is significantly different from zero. This result differs from the one obtained in the preceding model where there was some evidence of nonhomotheticity. It can, therefore, be conjectured that the incorporation of technical change has either suppressed or absorbed nonhomotheticity. We had alluded to such a possibility and this empirical result provides an example of this.

D. Changes in Input Relations

The trend in farm input prices in Canada and Western Canada over the past two decades can be divided into two different periods. From 1961 until the early 1970s, the rise in farm input prices was relatively slow. During the subsequent period from the early 1970s there were rapid increases in farm input prices and the 'energy crisis' became evident. In this section, the relationship between the various inputs is assessed over the periods of 1961 to 1970 and of 1971 to 1978. Input relationships are also estimated over the periods from 1961 to 1973 and from 1974 to 1978. The splitting of the entire time period in this manner enables study of the impact of inflation and of the 'energy crisis' on agriculture, and enables examination of whether capital-labour (i.e., machinery-labour) substitution relationships have changed in the more recent period.

The input relationships are examined by considering the signs and magnitudes of the translog estimates of AES. The

AES estimates for different periods for Canadian and Western Canadian agriculture are presented in Tables 5.27 and 5.28, respectively. It can be seen from both these tables that the signs of the estimates are consistent between each period.

The absolute values of the AES estimates for Canadian agriculture over the period 1971 to 1978 show some decline from those for 1961 to 1970 for all input pairs except for labour-machinery and labour-energy. In agriculture, machinery-labour substitutability may be regarded as the analog of capital-labour substitutability. The estimates of AES for labour and machinery show no evidence of a decline in machinery-labour substitutability in the period of rising energy prices.

The signs of the estimates for the subperiod 1961 to 1973 and the subperiod 1974 to 1978 are also found to be consistent. The estimates for 1974 to 1978 show some decline from those for the preceeding period of 1961 to 1973 for all input pairs except land-machinery, land-energy, and labour-energy. The extent of labour-machinery substitution shows a very small decline occurring over the later period.

The estimates for Western Canadian agriculture also show consistency in signs of AES between earlier and later periods. Five of the ten estimates of the absolute values of the AES for 1971 to 1978 show a decline compared to the estimates for 1961 to 1970. The AES between labour and machinery increases from .0553 to .0754. The evidence for the periods of 1961 to 1973 and 1974 to 1978 is similar. The

Table 5.27: Estimates of Elasticities of Substitution, 1961-70 and 1971-78, and 1961-73 and 1974-78, Canadian Agriculture[1]

Input Pair	1961-70	1971-78	1961-73	1974-78
Land-Labour	.0827^{++}	.0046^{++}	.0674^{++}	.0032^{++}
Land-Machinery	.9995	.8470	.8255	.8541
Land-Fertilizer	-1.5995^{++}	-.8472^{++}	-1.5098^{++}	-.6225^{++}
Land-Energy	-.3898^{++}	-.3155^{++}	-.3820^{++}	-.3666^{++}
Labour-Machinery	.3459^{++}	.3509^{++}	.3495^{++}	.3447^{++}
Labour-Fertilizer	-.5959	-.3096	-.5627	-.2117
Labour-Energy	2.3061^{++}	2.4282^{++}	2.2775^{++}	2.5634^{++}
Machinery-Fertilizer	4.0658^{++}	3.0000^{++}	3.9063^{++}	2.7593^{++}
Machinery-Energy	2.1194^{++}	1.9731^{++}	2.0599^{++}	2.0084^{++}
Fertilizer-Energy	-10.8126^{++}	-9.9419^{++}	-12.0945^{++}	-8.1584^{++}

[1] The estimates for these various sub-periods are based upon the basic homothetic single output model which incorporates technical change.

Table 5.28: Estimates of Elasticities of Substitution, 1961-70 and 1971-78, and 1961-73 and 1974-78, Western Canadian Agriculture[1]

Input Pair	1961-70	1971-78	1961-73	1974-78
Land-Labour	$-.4784^{++}$	$-.6244^{++}$	$-.5015^{++}$	$-.6514^{++}$
Land-Machinery	1.0182	1.0178	1.0181	1.0178
Land-Fertilizer	2.8090	2.1305	2.7339	1.9804
Land-Energy	$.2875^{+}$	$.2317^{+}$	$.2241^{+}$	$.2557^{+}$
Labour-Machinery	$.0553^{+}$	$.0754^{+}$	$.0573^{+}$	$.0813^{+}$
Labour-Fertilizer	.4217	.6395	.4449	.6890
Labour-Energy	3.3891^{+}	3.5699^{++}	3.6055^{++}	3.4760^{++}
Machinery-Fertilizer	6.7414	4.1960	6.4069	3.7089
Machinery-Energy	.7507	.7605	.7333	.7733
Fertilizer-Energy	-37.456^{++}	-22.5279^{++}	-38.5809^{++}	-18.3373^{++}

[1] The estimates for these various sub-periods are based upon the basic homothetic single output model which incorporates technical change.

estimates for the labour-machinery pair show a small increase in the magnitude of the AES for 1974 to 1978 compared to 1961 to 1973.

The estimates of AES between labour and machinery, from statistically significant input price coefficients, for both Canadian and Western Canadian agriculture over the period 1974 to 1978 indicate no perceptible decline. This result should not be interpreted that the 'energy crisis' did not have any impact on labour-machinery substitution, because in reality energy prices relative to most farm inputs did not increase prior to 1978. In future, as the price of energy relative to other farm input prices rises, whether machinery-labour substitution will be retarded remains an open question.

E. A Test of the Value Added Specification

The value added specification has been widely used in the analysis of factor substitution in production. The specification implies separability between primary and nonprimary inputs. The production function is often written as: $Y = F(K,L)$, where Y is output, K is capital and L is labour. In this widely used specification, output is shown to be a function of only the primary inputs of capital and labour. Intermediate inputs (also known as materials or purchased inputs) are excluded. Accordingly, any substitution possibilities between capital and labour are considered ignoring the material inputs. This is done under

the assumption that the nonprimary inputs bear some specific stringent relationship with the primary inputs. In this section, some conditions associated with this feature are examined to see whether these are satisfied for Canadian and Western Canadian agriculture. This enables the assessment of whether the inclusion of nonprimary inputs is justified in this study which has the five-input structure of land, labour, machinery, fertilizer, and energy.

A detailed discussion of the conditions under which it is valid to regard primary and nonprimary inputs as separable (and thus it is valid to consider substitution possibilities between such primary inputs as land, labour, and machinery, ignoring the intermediate inputs of, say, energy and fertilizer) is available in Berndt and Wood (1975). The conditions which are testable using the empirical estimates of AES can be stated as:

$$\sigma_{FN} = \sigma_{FL} = \sigma_{FM} = 1 \qquad (5.1)$$

$$\sigma_{EN} = \sigma_{EL} = \sigma_{EM} = 1 \qquad (5.2)$$

where N, L, M, F, and E refer to land, labour, machinery, fertilizer, and energy. According to (5.1), separability requires that the AES between fertilizer and the primary

inputs of land, labour and machinery are all equal to unity. Conditions (5.2) imply that similar conditions must also hold for the intermediate input of energy and for all primary inputs. These stringent conditions are clearly not satisfied by the estimates of AES obtained in this study. For example, with the estimates of the single output homothetic model for Canada (from Table 5.2)inserted in (5.1) and (5.2):

$$\begin{array}{lll l} -1.19^{++}, & -0.43, & 3.49^{++} & \neq 1 \\ -0.22^{++}, & 2.30^{++}, & 2.05^{++} & \neq 1 \end{array} \tag{5.3}$$

The corresponding figures for Western Canada (from Table 5.15) are:

$$\begin{array}{lll l} 2.42, & 0.54, & 5.28 & \neq 1 \\ 0.26^{+}, & 3.46^{++}, & 0.75 & \neq 1 \end{array} \tag{5.4}$$

It appears by inspection that the exclusion of intermediate inputs on the grounds of separability would not have been justified for the production structures of Canadian and Western Canadian agriculture.

F. Concavity, Positivity, and the Predictive Power of the Models

In this section, the well-behavedness of the translog models and their predictive performance are examined. A cost function is regarded as well-behaved if it is concave in input prices and if the estimated demand functions corresponding to it are strictly positive. Concavity is satisfied if the matrix of AES is negative semidefinite. This is tested by deriving and examining the characteristic roots of the AES matrix. Monotonicity is satisfied if the dependent variables (in this case, the cost shares) are all positive (Binswanger, 1974; Berndt and Wood, 1975).

The test for concavity relates to whether the estimates are stable. Lack of stability could imply significant structural changes and switches of techniques (Chotigeat,1978). In this study, concavity was satisfied for the homothetic single output and nonhomothetic single output models (without technical change) for Canada, and for the nonhomothetic model with technical change for Western Canada. The other model variations narrowly failed to satisfy the criterion of concavity. The potential problem of instability which is implied by the lack of concavity is not uncommon in flexible form studies on agriculture and was encountered by Chotigeat (1978) in his study of factor substitution in Thai agriculture, and implicitly by Sidhu and Baanante (1980). The period covered in this study was marked by major changes in the structure of input use in

Canadian agriculture and this could be responsible for the non-satisfaction of concavity which was encountered in some model variations.

Positivity can be studied by considering the signs of the predicted dependent variables. On the basis of the estimates obtained by using the constrained seemingly unrelated regression technique, all the estimated shares were found to be positive in all model variations for both Canada and Western Canada. Hence, the requirements for positivity, also known as monotonicity, were satisfied.

The predictive performance of the models can be evaluated by examining the relationship between actual and predicted values of the dependent variables. This is examined for each year during the period covered by this study. The predicted and actual values of the dependent variables in all four of the estimated equations were found to be quite close. The values of R^2 between the actual and the predicted cost shares for the inputs of land, labour, machinery, and fertlizer for all four model variations for Canada and Western Canada are given in Tables 5.29 and 5.30. Since the energy equation is deleted from estimation, values for this variable are not reported. In general, the values of R^2 are higher for Canada than for Western Canada. These values of R^2 indicate that the performance of the various model specifications used in this study is reasonable.

Table 5.29: R^2 Between Predicted and Actual Values of Dependent Variables, Canada, 1961-1978

Model	Land	Labour	Machinery	Fertilizer
Homothetic Single Output With Technical Change	.9026	.8845	.9001	.6784
Homothetic Joint Output With Technical Change	.9306	.9407	.9447	.7498
Nonhomothetic Single Output	.8699	.9515	.8935	.8540
Nonhomothetic Single OUtput With Technical Change	.9320	.9386	.9305	.7777

Table 5.30: R^2 Between Predicted and Actual Values of Dependent Variables, Western Canada, 1961-1978

Model	Land	Labour	Machinery	Fertilizer
Homothetic Single Output With Technical Change	.6201	.8395	.7090	.7636
Homothetic Joint Output With Technical Change	.6289	.8283	.7294	.7704
Nonhomothetic Single Output	.6087	.8113	.6319	.7819
Nonhomothetic Single OUtput With Technical Change	.6182	.8329	.7141	.7603

G. Summary

The major empirical results of this chapter are summarized below:

1. There is a considerable amount of factor substitution (and, in some cases, complementarity) in both Canadian and Western Canadian agriculture.
2. Empirical estimates of factor substitution in terms of AES overwhelmingly reject both the Leontief (zero elasticity of substitution) and Cobb-Douglas (unitary elasticity of substitution) specifications.
3. Own price elasticities of demand were mostly found to be less than unity which implies an inelastic demand for farm inputs.
4. There is strong evidence of augmented technical change in both Canadian and Western Canadian agriculture. An interesting feature is the simultaneous presence of both land- and labour-augmenting technical change.
5. Nonhomotheticity appears to be present in the production structure of both Canadian and Western Canadian agriculture. The extent of nonhomotheticity was found to be greater in Canadian than in Western Canadian agriculture.
6. Evidence of augmented technical change was found for both the homothetic and the nonhomothetic models.
7. The value added specification was clearly rejected on the evidence of the estimated AES values.
8. The relationships among inputs remained stable during

the periods 1961 to 1970 and 1971 to 1978. These also remained stable for the periods 1961 to 1973 and 1974 to 1978. There were some slight changes in the magnitudes of the AES values.

9. There was no clear evidence of a decline in machinery-labour substitution in the periods mentioned above of which the most recent periods in the 1970s included the so-called 'energy crisis'. On the contrary, there was evidence of an increase in machinery-labour substitution in Western Canada.

10. Statistically, the models performed fairly well. In general, the performance was better for Canada as a whole than for Western Canada.

11. The test for concavity indicated the presence of some instability in the estimates obtained. This could perhaps be due to major changes in the use of various inputs in Canadian agriculture. The test of positivity (monotonicity) was satisfied for all model variations.

12. The predictive power of the models was found to be reasonably satisfactory as indicated by the relationships between actual and predicted cost shares.

VI. PRODUCTIVITY CHANGE IN CANADIAN AGRICULTURE

Recent research developments in the study of productivity measurement (Christensen, 1975; Diewert, 1976; Brown, 1978) have emphasized two things: the superiority of total factor productivity (TFP) indexes and the use of flexible weight indexing procedures. Despite these developments and some work in these directions on the agricultural sectors of the U.S.A., Australia, and some Asian countries, existing research work on Canadian agriculture has not incorporated both these approaches simultaneously. In this chapter, an attempt is made to fill this gap by providing TFP indexes based on flexible weight indexing procedures for the Canadian agricultural sector. Besides TFP indexes, indexes of partial factor productivity (PFP) are also provided to examine the adequacy of this approach. The development of improved measures of productivity growth in Canadian agriculture is needed to show whether, in fact, productivity growth has declined or approached zero during the 1970s.

A. Partial and Total Factor Productivity

Productivity measures can be divided into two categories--partial and total. Partial factor productivity (PFP) is defined as the ratio of output to a particular input and includes such frequently used measures as output

per acre (yield) and output per unit of labour. Total factor productivity, on the other hand, is defined as the ratio of output to all inputs. The latter measure has become popular in recent years and is a better indicator of physical (or technical) efficiency gains in production.

Although PFP measures are widely used, these have several limitations. PFP measures which apply to a particular input may not adequately represent the extent of productivity growth. In Canadian agriculture, for example, PFP with respect to labour increased appreciably during the period 1961 to 1978. This is due to the fact that the amount of farm labour and the number of hours worked have declined whereas various crop outputs and total agricultural output have increased considerably. It is, however, misleading to attribute increases in output solely to labour since this ignores the contribution of the increasing use of other inputs in the production process. While productivity in terms of output per unit of labour shows significant increases, evidence of much slower growth in productivity is likely when the TFP approach is adopted. In Canadian agriculture, the increase in labour productivity which has been associated with the decline in labour input has also been associated with increases in other factors--that is, labour has been replaced by capital and purchased inputs (materials). Similarly, output per unit of land (yield) measures can be misleading indicators of productivity growth since they implicitly ignore the role of improved methods of

cultivation (through the use of machinery and through the use of better seeds, fertilizer, and other chemical inputs). The degree of factor substitution and the relative weights and costs of various inputs over time are thus very important questions, but these are precisely the questions which tend to be passed over through the use of partial productivity measures and Laspeyres indexing procedures. In particular, it is necessary to consider all inputs to generate a realistic measure of productivity growth.

B. Economic Theory of Productivity Measurement

There are two basic types of indexing procedures available for constructing indexes of output and inputs whose ratio gives the index of productivity. The first of these is the fixed weight approach to which belongs the Laspeyres and Paasche indexes, while the second is the flexible weight approach of which the Divisia index and its discrete Tornqvist approximation are the most well known. These two indexing procedures and the question of measurement of the input labour are discussed below.

The Laspeyres or Fixed Weight Approach

The Laspeyres index is widely used and is the indexing formula generally used by Statistics Canada. The Laspeyres quantity index can be written as:

$$Q(t) = \frac{\Sigma p(0)q(t)}{\Sigma p(0)q(0)} \tag{6.1}$$

where $Q(t)$ is the quantity index in period t, q's and p's are item quantities and prices, and 0 and t refer to base and current year, respectively. Equation (6.1) can be rewritten in the following way:

$$Q(t) = \frac{\Sigma[q(t)/q(0)]\ p(0)q(0)}{\Sigma[p(0)q(0)]} \tag{6.2}$$

It can be seen from (6.1) and (6.2) that since price is held fixed at the base period level, only quantity data for subsequent years are necessary for the construction of the index. Because of this, empirical implementation of the Laspeyres index becomes greatly simplified.

Despite its wide use, the Laspeyres index has several limitations. The Laspeyres index implies a linear production function (Christensen, 1975). This, in turn, implies that all factors are perfect substitutes. The Laspeyres index is also sensitive to the choice of a base period. In Canada, as elsewhere, agricultural production and prices are characterized by wide ranging fluctuations. In such circumstances, the choice of a particular year or period as

the fixed base of the index may give a misleading picture of the extent of change in later years.

The Divisia or Flexible Weight Approach

The Divisia indexing procedure provides a solution to the above problems. Proposed by Divisia (1926), it involves a flexible weight method. The continuous version of the Divisia index can be written as:

$$Q(t)/Q(0) = \exp \{\int[w_i(t)\ (\dot{q}_i(t)/q_i(t)\ )]\}$$

$$\text{where}\quad w_i(t) = [p_i(t)q_i(t)]/\Sigma p_j(t)q_j(t)] \tag{6.3}$$

The foregoing weight, w(t), may be regarded as the share of the i-th factor in total cost or the share of the i-th output in total value as the case may be. Equation (6.3) is given in continuous terms. For empirical implementation, it is necessary to use a discrete approximation. The approximation which is most widely used was proposed by Tornqvist (1936). The Tornqvist approximation to the Divisia quantity indexes corresponding to (6.3) is given by:

$$\log Q_t - \log Q_{t-1} = \Sigma\bar{w}_{it}\ (\log q_{it} - \log q_{i,t-1}) \tag{6.4}$$

The weights (w) in both price and quantity indexes are the

same. A given weight is the arithmetic mean of the shares in two adjacent periods and can be written as:

$$w_{it} = 1/2(w_{it} + w_{i,t-1}) \tag{6.5}$$

In (6.5), the weights are flexible over time as shares change.

The Tornqvist approximation to the Divisia index which has been chosen for estimation of productivity change is consistent with the choice of functional form (translog) which is used for studying factor substitution in Canadian agriculture. Various theoretical properties of the Divisia index are discussed by Hulten (1973) and technicalities of the link between this index and functional forms in production are elaborated by Diewert (1976). The economic implications of these relationships in relation to the Laspeyres index were discussed by Christensen (1975: 911) in the following words:

> The basic difference between the Laspeyres and Tornqvist (and other superlative) indexes is that the Laspeyres index holds prices fixed at their base period levels, while the Tornqvist index uses the prices from both the base period and the comparison period.
> The use of fixed base period prices in the Laspeyres index can be interpreted in terms of the linear production function. If there is perfect substitutability among factors of production, then an increase in the relative price of any input would cause discontinuation of its use. If a perfect substitute is available at a lower price, there is no rationale for using a higher priced input. If all inputs are used in both the base period and the

> comparison period, it follows that relative prices are the same in both periods. There is no need to consider the comparison periods since they are unchanged from the base period.

The limitations of the Laspeyres indexing procedure and their implications are clear from the above discussion. In contrast to the linear function implied by the Laspeyres index, the translog function is free from the restriction of perfect or any *a priori* fixed magnitude of factor substitution. The Tornqvist indexing procedure can accommodate the flexibility of the translog function. The rationale of this link was clarified by Christensen (1975: 911-912) thus:

> The translog function does not require inputs to be perfect substitutes. If the relative price of an input increases, the producer decreases its use (substituting other inputs) until all marginal productivities are proportional to the new prices. Hence, the prices from both periods enter the Tornqvist index to represent the marginal productivities in both periods.

This study spans eighteen years during which input prices and intensities changed. The Tornqvist indexing procedure which is flexible enough to study changing input use when factor substitution is taking place is used to analyze these changes.

The Star-Hall Approximation

The construction of Divisia indexes requires both price and quantity data for each year in the time period. This makes their empirical implementation more difficult. An alternative method of obtaining productivity growth rates using data from two end points of a long period has been

proposed by Star and Hall (1976). The Star-Hall index can be written as:

$$A(t) = \frac{Y(t)/Y(0)}{\prod_{i=1}^{n} [x_i(t)/x_i(0)]w_i} \tag{6.6}$$

where A(t) is the rate of change in productivity, Y(t), Y(0), x(it), and x(i0) refer to indexes of output and inputs in the current and base period respectively, and w(i) is the weighted average of the factor shares. The appropriate weighted share, w*(i), is given by:

$$w_i^* = \frac{1}{t} \int_0^t w_{it} \frac{g_i(t)}{g_i'} \tag{6.7}$$

where g(i) is the growth rate of input i and g'(i) is its average rate of growth over the period under consideration. Star and Hall proposed to approximate the true value of w by the arithmetic mean of w at the two end points. Hence, w*(i) is given by:

$$w_i^* = 1/2[w_i(0) + w_i(t)] \tag{6.8}$$

where w(0) and w(t) are shares at the beginning and at the

end, respectively, of the period. Substituting (6.8) into (6.6), the following expression for the rate of annual change in productivity can be derived:

$$A = \frac{Y(t) / Y(0)}{\prod_{i=1}^{n} [x_i(t) / x_i(0)] \; 1/2[w_i(0) + w_i(t)]} \tag{6.9}$$

The reliability of the Star-Hall measure, therefore, depends on the stability of the shares, w(i). If the shares are stable, the average of the two end points will be quite close to the weighted average of all values.

Measurement of the Labour Input

An important issue in generating productivity estimates is proper measurement of the input labour which, on a cost share basis, still remains the most important of all farm inputs. Traditionally, the persons employed concept has been used to measure labour input. This measure cannot adequately represent seasonality of employment and may generate an overestimate of labour use. A more satisfactory approach, though difficult to implement empirically, is to use total hours worked data. Although manhours data provided by Statistics Canada have some limitations and are more suspect to errors than persons employed data, the manhours data are used to obtain a new set of estimates of productivity growth

because the manhours concept is conceptually superior. [1] In this study, a set of estimates based on persons employed data is also provided for Canada as a whole. All indexes of inputs and productivity, except those reported in Tables 6.2 and 6.3, are based on manhours data.

C. A Survey of Previous Studies

This survey of previous studies of agricultural productivity measurement is divided into two parts. In the first part, studies of agricultural productivity in Canada are surveyed. In the second part, some of the studies which have used flexible weight indexing procedures in the measurement of agricultural productivity are summarized.

In its key publication on productivity, *Aggregate Productivity Measures (14-201)*,[2] Statistics Canada provides only a partial productivity index with respect to labour. In justifying this approach, Statistics Canada (1979: 17) says:

> In a general sense, a productivity index is a measure of the change in efficiency of an economy in combining resources to provide its output. Ideally, all resources should be counted as inputs. At the present stage of development, only labour inputs can be measured.

It appears that the difficulties encountered by by Statistics Canada in considering inputs other than labour and constructing TFP indexes refer to the problems of collecting and manipulating data for all sectors of the

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[1] See Brown(1978) for a good discussion of this point.
[2] The number in parentheses indicates the Statistics Canada catalogue number.

economy. In previous studies of Canadian agriculture (Furniss, 1970; Shute, 1975), however, inputs other than labour have been considered in constructing TFP indexes.

In *Aggregate Productivity Measures (14-201)*, productivity is defined as the ratio of indexes of real output and labour input:

$$AL(t) = \frac{Q(t)/Q(0)}{L(t)/L(0)} \times 100 \tag{6.10}$$

where AL(t) is the index of labour productivity and Q and L are constant price output and volume of labour input (persons employed or manhours), respectively. The subscripts 0 and t refer to base and current years.

The concept of real domestic product used in (6.10) is the same as that in *Indexes of Real Domestic Product by Industry* (61-506). In that publication, a Laspeyres fixed weight index is used to construct aggregate output indexes. Since this measure is used for the numerator (Q) in (6.10) above, this form of measure presumably is used in obtaining the index of labour input (L). It seems evident, then, that the method of productivity measurement adopted by Statistics Canada incorporates neither total factor productivity

aproaches nor flexible weight indexing methods.

Recent productivity studies on Canadian agriculture include those by Furniss (1970), Shute (1975), and Auer (1969).[3] Of these, the first two authors adopted a TFP approach, whereas the last author considered partial productivity with respect to labour.

One of the early studies of total factor productivity in Canadian agriculture was conducted by Furniss (1970). He found evidence of considerable productivity growth in Canadian agriculture during the period considered. This study concluded that TFP in Canadian agriculture increased by 2.0 percent per year during the period 1949 to 1969 and by 2.5 percent per year between 1959 and 1969.

Shute (1975) updated Furniss' work in her study of agricultural productivity in Canada and in its different regions. She reported an annual growth rate of productivity of 0.86 percent for Canadian agriculture and of 1.17 percent in the prairies for the period 1961 to 1974. When the year 1961--a drought year in the prairies--was excluded, the Canadian productivity growth rate fell to 0.07 percent, while the prairie growth rate was estimated to be negative (-0.35 percent). This is a clear example of the sensitivity of productivity growth rate estimates to the inclusion or exclusion of a year of poor weather.

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[3] In an earlier work, Lok (1961) studied productivity change in Canadian agriculture for the period 1926 to 1957.

Shute used a simple method of constructing indexes. She defined productivity as the ratio of price deflated output and price deflated inputs. Although she used a very simple framework of analysis, Shute (1975: 1) emphasized the need for adopting a TFP approach by saying:

> The fact that output per unit of labour input has increased continually since 1961 is of no satisfaction if the increased capital inputs required to offset the labor loss over-ride the importance of the increased output.

Auer (1969) studied the productivity of labour using a PFP approach. He found that the partial productivity of labour in Canadian agriculture increased at the yearly rate of 5.5 percent for the period 1947 to 1965. This is comparable to our estimate of an annual growth rate of productivity of labour of 4.81 percent for the later period 1961 to 1978.

Recent studies which have used the Divisia indexing method to study agricultural productivity include those of Lee and Chen (1978) on Taiwan, Brown (1978) on the United States, and Lawrence and McKay (1980) on Australia.

Lee and Chen (1978) studied productivity growth in Taiwan's agriculture using both total and partial productivity approaches. The computational procedure used in applying the Tornqvist approximation to the Divisia index is slightly different from the method now in use. As well, the shares used by Lee and Chen are five year averages rather than the more fully flexible schemes now in use as indicated above in equations (6.4) and (6.5).

In his doctoral dissertation, Brown (1978) conducted an extensive study of productivity in U.S. agriculture using the TFP approach. Applying the Tornqvist index of the type given in (6.4), he obtained an annual rate of productivity growth of 1.15 percent which was the difference between the growth rate in output (1.79 percent) and inputs (0.64 percent) for the period 1947 to 1974. When he divided the period into two parts, he obtained a growth rate of productivity of 1.98 percent for 1947 to 1960 and 0.39 percent for 1960 to 1974. Brown also applied the Star-Hall index of equation (6.9). Using data for the two end points only (1947 and 1974), he derived a growth rate of productivity of 1.14 percent which was nearly identical to the growth rate of 1.15 percent obtained by using data for all years.

In a recently published paper, Lawrence and McKay (1980) examined productivity changes in the Australian sheep industry. This is a fairly disaggregated study which used both TFP and PFP approaches. The TFP growth rate was 2.9 percent per year between the years 1952-1953 and 1976-1977. This was the difference between the annual growth rate in output (4.4 percent) and the annual growth rate in inputs (1.5 percent). The authors also provided estimates of the terms of trade, defined as the ratio of prices received and prices paid by the sheep industry, and estimates of a returns to costs ratio, defined as the index of the ratio of value of output to the value of inputs. They found that the

returns to costs ratio declined by 1.2 percent yearly during the period of their study. Both these estimates suggested that the producers in the sheep industry in Australia were deprived of a large portion of the benefits of productivity gain.

D. Estimates for Canada

The estimates of indexes of aggregate output and aggregate input as well as indexes of total and partial factor productivity for Canada are reported below. In order to obtain an index of TFP, it is necessary first to construct quantity indexes of output and all inputs. The output and input indexes are constructed using the Tornqvist approximation to the Divisia index as given in equation (6.4) and using the arithmetic average of the shares in two adjacent periods.

Indexes of Output, Inputs, and Productivity

The quantity index of all agricultural output was derived by combining aggregate crop and livestock indexes. Twelve principal crops were considered in constructing the aggregate crop index.[4] These were: wheat, oats, barley, rye, mixed grain, corn for grain, flax seed, soybeans, mustard seed, rape seed, potatoes, and tame hay.

Price and quantity data for these crops were obtained from several Statistics Canada sources including *Handbook of*

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[4]This list of principal crops is the same as the one used in Agriculture Canada publication *Selected Agricultural Statistics*.

Agricultural Statistics (21-516), Quarterly Bulletin of Agricultural Statistics (21-003), Field Crop Reporting Series (22-003), and the Agriculture Canada publication, *Selected Agricultural Statistics for Canada (1980)*. Some of the data were also retrieved from *CANSIM* which is the computerized data bank of Statistics Canada.

The Divisia quantity index for all crops with base year 1971 is presented in column 1 of Table 6.1. This and the other indexes are reported for the period 1961 to 1978. Following Pesek (1961), Griffin (1974), and Veeman (1975), annual growth rates were computed from yearly values of the index by fitting the following trend line by regression:

$$\ln G(t) = a + bt + u \tag{6.11}$$

where G(t) refers to the variable under consideration, and t and u denote time and stochastic error term, respectively. In this formulation, the compound growth rate is derived as the antilog of the estimated coefficient on time minus one.

The all crop index shows an annual growth rate of 2.69 percent for the period 1961 to 1978. As can be seen from Table 6.1, crop production is characterized by wide ranging fluctuations with below normal years such as 1961, 1967, and 1974, and above normal years such as 1962, 1966, 1971, and 1978. When the year 1961 is excluded, the annual growth rate associated with the crop index falls to 1.87 percent. The

quantity index of livestock production, given in column 2 of Table 6.1, is composed of seven items. These are: cattle and calves, sheep and lambs, pigs, chicken and fowl, turkeys, eggs, and dairy. Livestock production data were collected from the Statistics Canada sources *Handbook of Agricultural Statistics (21-516), Livestock and Animal Product Statistics (23-202)*. Agriculture Canada publications, *Selected Agricultural Statistics for Canada* and *Livestock and Market Review*, were also used.

Livestock production grew at a slower rate than crop production, increasing by 1.42 percent per year over the period 1961 to 1978. Compared to crop production, fluctuations in livestock production were more limited. As a result, the pattern of fluctuations in total agricultural output was largely determined by fluctuations in crop production.

The index of total agricultural production which is reported in the last column of Table 6.1 is constructed by combining crop and livestock indexes. The index of agricultural output stood at 0.619 in 1961 compared to 1.086 in 1978. This implied a growth rate of 2.01 percent per year. For the period 1962 to 1978, the growth rates were 1.78, 1.34, and 1.52 percent for crops, livestock,and all output, respectively.

The index of farm inputs, reported in Table 6.2, is composed of capital, labour, and intermediate inputs (purchased inputs or materials). These input categories are

Table 6.1: Divisia Quantity Indexes of Agricultural Output, Canada, 1961 to 1978 (1971=1.000)

Year	Crops	Livestock	All Output
1961	.487	.819	.619
1962	.745	.823	.779
1963	.861	.848	.860
1964	.751	.893	.809
1965	.832	.922	.871
1966	.992	.921	.969
1967	.796	.940	.861
1968	.874	.953	.910
1969	.928	.951	.938
1970	.851	.988	.915
1971	1.000	1.000	1.000
1972	.901	1.010	.948
1973	.947	.995	.972
1974	.826	1.012	.900
1975	.857	1.036	.987
1976	1.013	1.038	1.015
1977	1.069	1.042	1.044
1978	1.175	1.033	1.086
Annual Growth Rates(%)			
1961-78	2.69	1.42	2.01
1962-78	1.87	1.34	1.52

Table 6.2: Divisia Quantity Indexes of Farm Inputs (Using Persons Employed Labour Data), Canada, 1961 to 1978 (1971=1.000)

Year	Capital	Labour	Materials	All Inputs
1961	.866	1.335	.653	.905
1962	.874	1.289	.668	.902
1963	.894	1.262	.723	.927
1964	.921	1.242	.767	.950
1965	.955	1.171	.801	.959
1966	.968	1.074	.865	.962
1967	.996	1.010	.928	1.002
1968	1.014	1.068	.922	.999
1969	1.023	1.048	.919	.995
1970	1.035	1.003	.955	.993
1971	1.000	1.000	1.000	1.000
1972	.999	.944	1.066	1.003
1973	1.019	.919	1.056	1.000
1974	1.075	.931	1.018	1.010
1975	1.019	.957	1.037	1.036
1976	1.152	.935	1.084	1.063
1977	1.151	.922	1.130	1.073
1978	1.199	.937	1.196	1.117
Annual Growth Rates (%)				
1961-78	1.61	-2.26	3.28	1.00
1962-78	1.58	-2.61	3.12	0.98

composed of: capital--land, machinery, and livestock; labour--hired, unpaid family workers, and farm operators; and materials--fertilizer, energy, seeds, and feeds. Some of these components have several subcomponents. For example, land consists of improved and unimproved land, and energy is the combination of petroleum products and electricity.

Necessary data for constructing input indexes were collected and derived from various Statistics Canada publications and *CANSIM*. The publications consulted included *Census of Canada, Agriculture, 1976 (96-800); Quarterly Bulletin of Agricultural Statistics (21-003); Farm Implement and Equipment Sales (63-203); The Labour Force (71-001); Labour Force Annual Averages (71-529); Farm Wages in Canada (21-002); The Farm Input Price Index (62-004); The Fertilizer Trade (46-207); Refined Petroleum Products (45-208); and Farm Net Income (21-202)*. Agriculture Canada publications used were: *Selected Agricultural Statistics for Canada (1980); Market Commentary, Farm Inputs (1979);* and *Fertilizer Statistical Bulletin (1979).*

The index of capital rose from 0.866 in 1961 to 1.199 in 1978 while the index of materials increased from 0.653 to 1.196 over the same period. The index of labour (persons employed) fell from 1.335 in 1961 to 0.937 in 1978. It is quite clear that factor substitution took place between the labour input and other durable inputs (capital) and nondurable inputs (materials).

The index of aggregate farm inputs is shown in the last column of Table 6.2. This index rose from 0.905 in 1961 to 1.117 in 1978. The overall growth of all inputs over 1961 to 1978 was 1.00 percent which implies that the fall in the labour input was more than offset by growth in the other two categories of inputs.

Total factor productivity (TFP) is defined as the ratio of the index of output and the index of all inputs. The TFP indexes for Canadian agriculture are reported in Table 6.3. The growth rate of TFP over 1961 to 1978 was 1.01 percent per year. Growth in productivity is that part of the growth in output which is not explained by growth in inputs. This is, therefore, the difference between the growth rates of output and inputs. For the period 1962 to 1978, the growth rate in output was only 1.52 percent. This implies, given the input growth rate of 0.98 percent, a TFP growth rate of only 0.54 percent. Thus, the exclusion of the drought year 1961 significantly affects the estimate of the productivity growth rate.

The estimates which follow and all subsequent productivity estimates are based on manhours data. Manhours data and the hourly wage rate without board were used to construct a Divisia index of farm labour which was then combined with other inputs to generate a new aggregate input index. The new input index is reported in Table 6.4 and the resulting productivity index is presented in Table 6.5. The estimates show a slower growth rate in the aggregate input

Table 6.3: Indexes of Agricultural Output, Inputs, and Total Factor Productivity (Using Persons Employed Labour Data), Canada, 1961 to 1978 (1971=1.000)

Year	Output	Inputs	Productivity
1961	.619	.905	.684
1962	.779	.902	.864
1963	.860	.927	.928
1964	.809	.950	.851
1965	.871	.959	.908
1966	.969	.962	1.007
1967	.861	1.002	.859
1968	.910	.999	.911
1969	.938	.995	.943
1970	.915	.993	.921
1971	1.000	1.000	1.000
1972	.948	1.003	.945
1973	.972	1.000	.972
1974	.900	1.010	.891
1975	.987	1.036	.953
1976	1.015	1.063	.955
1977	1.044	1.073	.973
1978	1.086	1.117	.972
<u>Annual Growth Rates</u>(%)			
1961-78	2.01	1.00	1.01
1962-78	1.52	0.98	0.54

Table 6.4: Divisia Quantity Indexes of Farm Inputs (Using Manhours Data), Canada, 1961 to 1978 (1971=1.000)

Year	Capital	Labour	Materials	All Inputs
1961	.866	1.427	.653	1.013
1962	.874	1.373	.668	.999
1963	.894	1.334	.723	1.010
1964	.921	1.276	.767	1.011
1965	.955	1.188	.801	1.000
1966	.968	1.101	.865	.991
1967	.996	1.116	.928	1.025
1968	1.014	1.065	.922	1.009
1969	1.023	1.053	.919	10065
1970	1.035	.999	.955	.998
1971	1.000	1.000	1.000	1.000
1972	.999	.929	1.066	.987
1973	1.019	.931	1.056	.991
1974	1.075	.949	1.018	1.004
1975	1.019	.970	1.037	1.028
1976	1.152	.940	1.084	1.042
1977	1.151	.895	1.130	1.034
1978	1.199	.897	1.196	1.067
Annual Growth Rates (%)				
1961-78	1.59	-2.80	3.23	0.19
1962-78	1.31	-2.66	3.09	0.22

Table 6.5: Indexes of Agricultural Output, Inputs, and Total Factor Productivity (Using Manhours Data), Canada, 1961 to 1978 (1971=1.000)

Year	Output	Inputs	Productivity
1961	.619	1.013	.611
1962	.779	.999	.780
1963	.860	1.010	.851
1964	.809	1.011	.800
1965	.871	1.000	.871
1966	.969	.991	.978
1967	.861	1.025	.840
1968	.910	1.009	.902
1969	.938	1.006	.932
1970	.915	.998	.917
1971	1.000	1.000	1.000
1972	.948	.987	.960
1973	.972	.991	.981
1974	.900	1.004	.896
1975	.987	1.028	.960
1976	1.015	1.042	.974
1977	1.044	1.034	1.010
1978	1.086	1.067	1.018
<u>Annual Growth Rates</u>(%)			
1961-78	2.01	0.19	1.83
1962-78	1.52	0.22	1.31

index than in the aggregate input index based on persons employed data. The aggregate input index based on the manhours labour concept increased by 0.19 percent per year. This implied a productivity growth rate of 1.83 percent per year for the period 1961 to 1978. When the drought year 1961 is excluded, the growth rate in output dropped to 1.52 percent, the overall input growth rate rose slightly to 0.22 percent, and the resulting growth rate in productivity was 1.31 percent.

The manhours data implied a higher share of labour in total input cost than did the persons employed figures used for the previous estimates presented in Table 6.3. As a result, the absolute and relative fall in labour input had a greater impact on the estimated aggregate input index. This implied a slower growth in aggregate input which, since the output index remained the same, implied a higher growth rate in productivity. Given the conceptual superiority of manhours data, the estimates presented in Table 6.5 may be regarded as more reliable indicators of productivity growth in Canadian agriculture. The tradeoff in measuring the labour input involves the conceptual superiority of the manhours concept against the likely greater empirical reliability of persons employed figures. In this study, more emphasis is placed on the former aspect.

Estimates of productivity growth rates are quite sensitive to the period covered. This can be seen from annual productivity growth rates in percentage terms for

several subperiods given below:

1962-70	1.89
1962-71	2.12
1962-72	1.97
1971-78	0.51
1972-78	1.14
1973-78	1.61

During the earlier sub-periods, productivity growth rates in Canada are estimated to be between 1.89 percent and 2.12 percent per year. In the later sub-periods, the annual growth rates were between 0.51 percent and 1.61 percent. These estimates indicate a slight slowing of productivity growth rates during the later periods though there is no indication that these rates approached zero.

The indexes of output, input, and productivity based on persons employed and manhours data are graphically presented in Figures 6.1 and 6.2, respectively. Since aggregate input use grew very slowly, fluctuations in productivity growth were very similar to the fluctuations in aggregate output. Until 1974, movements of output and productivity were nearly identical. After 1974, output grew at a faster rate than productivity apparently as a result of slightly higher increases in the aggregate input index.

Estimates of productivity growth based on the Laspeyres index using the same data base were made for Canadian agriculture. These are reported in Table 6.6. The Laspeyres based growth rates were found to be lower than the

Table 6.6: Laspeyres Based Indexes of Agricultural Output, Inputs, and Total Factor Productivity, Canada, 1961 to 1978 (1971=1.000)

Year	Output	Inputs	Productivity
1961	.641	.927	.691
1962	.784	.921	.851
1963	.855	.940	.909
1964	.817	.952	.858
1965	.874	.953	.917
1966	.959	.960	.999
1967	.863	1.000	.863
1968	.911	.989	.921
1969	.939	.987	.951
1970	.915	.991	.923
1971	1.000	1.000	1.000
1972	.952	1.008	.944
1973	.969	1.011	.958
1974	.912	1.017	.897
1975	.995	1.041	.956
1976	1.025	1.066	.961
1977	1.056	1.073	.984
1978	1.108	1.116	.993
Annual Growth Rates(%)			
1961-78	2.03	0.94	1.09
1962-78	1.61	0.95	0.66

FIGURE 6.1: INDEXES OF AGRICULTURAL OUTPUTS, INPUTS AND TOTAL FACTOR PRODUCTIVITY (USING PERSONS EMPLOYED LABOUR DATA), CANADA, 1961 TO 1978 (1971=1.000)

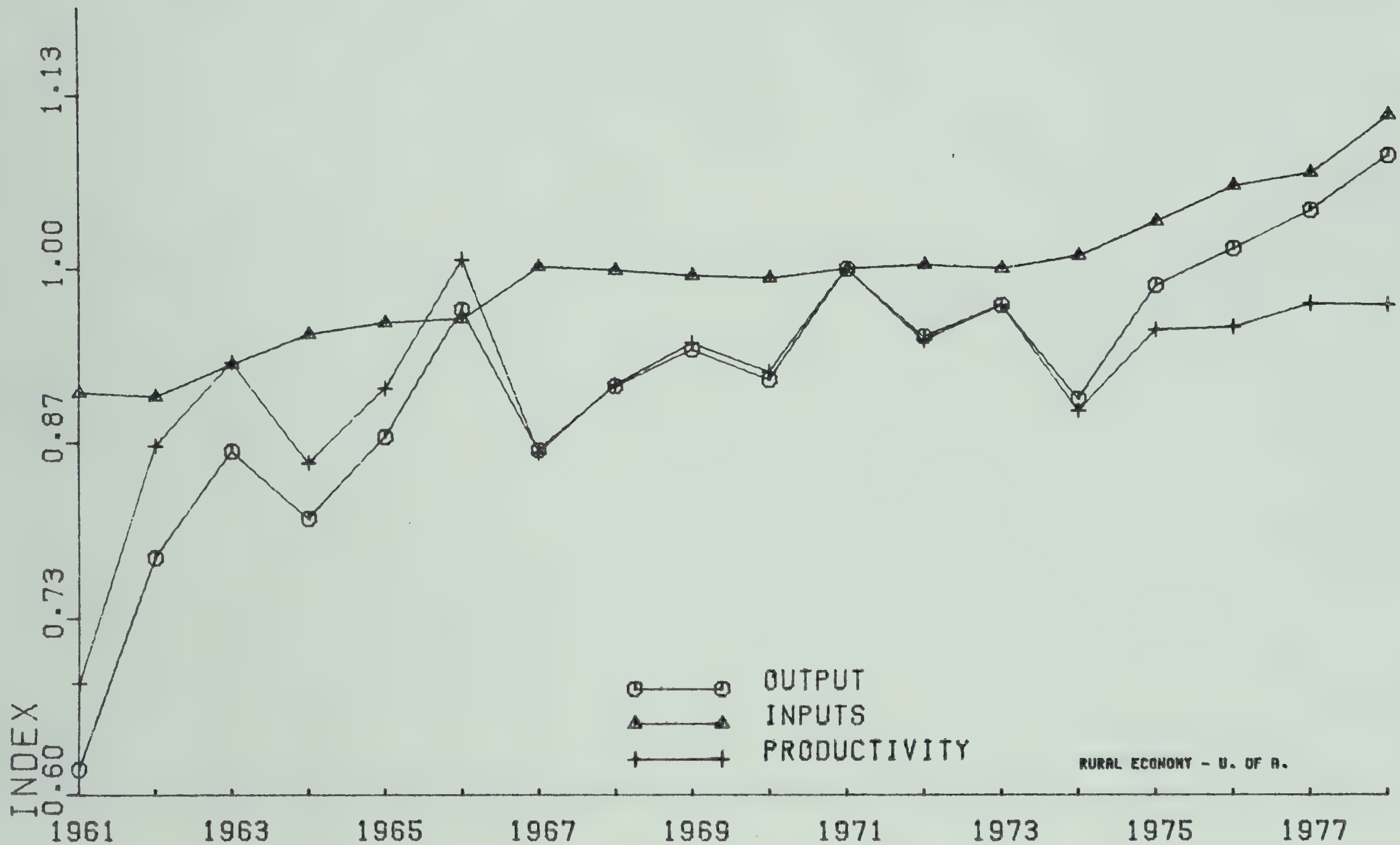
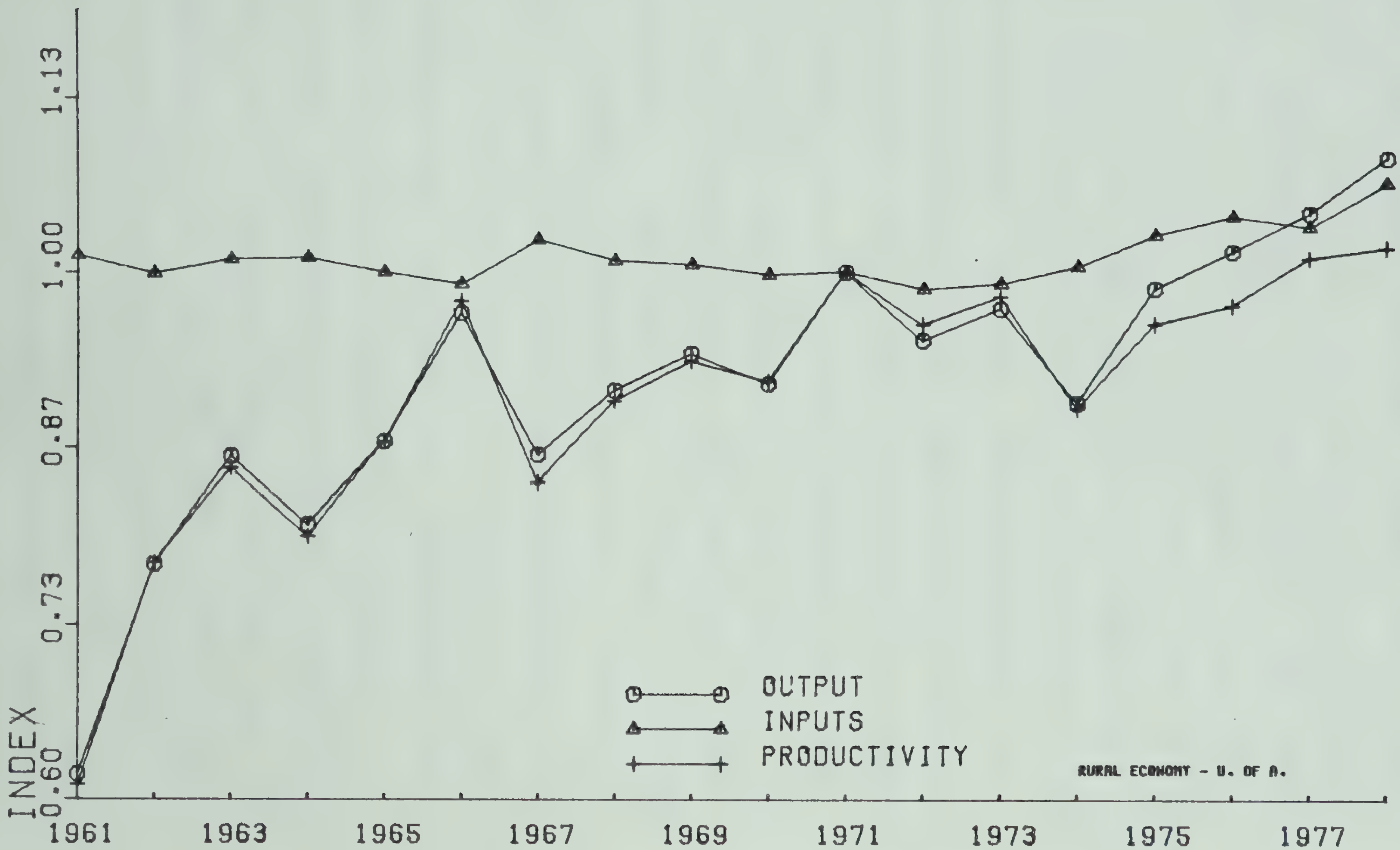


FIGURE 6.2: INDEXES OF AGRICULTURAL OUTPUT, INPUTS, AND TOTAL FACTOR PRODUCTIVITY (USING MANHOURS DATA), CANADA, 1961 TO 1978 (1971=1.000)



corresponding Divisia estimates for both the 1961-78 and 1962-78 periods.

The Star-Hall method, discussed above, was also used to obtain productivity growth rates in Canadian agriculture. Using data on two end points (1961 and 1978 or 1962 and 1978) from Tables 6.1, 6.4, and 6.7, annual productivity growth rates of 1.91 and 1.58 percent were obtained for the periods of 1961 to 1978 and 1962 to 1978, respectively. The Star-Hall growth rates given above are quite close to those obtained using data for all years. The differences that remain can be explained by examining the weight used in the Star-Hall method. In the Star-Hall procedure, an arithmetic average of factor shares in the two end points was used. If the factor shares do not change over time, the growth rate obtained by the Tornqvist and Star-Hall methods would be exactly the same. If the factor shares change, as has been the case in Canadian agriculture (indicated in Table 6.7), the Star-Hall growth rate differs from that based on the Tornqvist procedure. The difference in growth rates obtained by the two methods can, therefore, be explained by the fluctuating factor shares in Canadian agriculture.

The Star-Hall approach can only give an approximate annual growth rate in productivity. It does not trace the change in productivity in the intervening period. However, when data for every year are not available or are too expensive to obtain, the Star-Hall approximation can be used to obtain a fairly representative estimate of productivity

Table 6.7: Shares of Capital, Labour, and Materials in Total Cost, Canadian Agriculture, 1961 to 1978

Year	Total Cost[1]	Capital	Labour	Material
1961	3234.3	.232	.549	.228
1962	3285.1	.250	.511	.239
1963	3424.0	.256	.494	.249
1964	3573.9	.273	.474	.253
1965	3606.4	.287	.450	.263
1966	3798.4	.294	.430	.276
1967	4256.9	.307	.422	.270
1968	4358.1	.326	.409	.265
1969	4501.4	.331	.419	.250
1970	4562.0	.333	.411	.256
1971	4612.7	.304	.425	.271
1972	4843.6	.317	.405	.277
1973	5739.2	.314	.383	.303
1974	7065.7	.318	.372	.310
1975	8494.8	.323	.387	.289
1976	9510.5	.361	.376	.262
1977	9986.5	.345	.376	.279
1978	10843.4	.353	.366	.280

[1]Includes both actual and imputed cost, reported in millions of current dollars.

growth using data from two end points only.

Partial Factor Productivity

Partial factor productivity (PFP) is defined as the ratio of total output to the quantity of a particular input. In this section, estimates of PFP with respect to three broad categories of inputs--labour, capital, and materials--are reported. The main objective of this exercise is to examine the adequacy of the PFP approach to productivity measurement.

Estimates of the indexes of partial productivity of labour, capital, and materials and their annual growth rates are reported in Table 6.8. The growth rate of labour productivity is the highest, rising by 4.81 percent during the period 1961 to 1978. The growth rate of the productivity of capital was only 0.69 percent while the growth rate of materials productivity was negative (-1.11).

In Canadian agriculture, the relative and absolute decline in the input of labour (at least until the early 1970s) was more than offset by increases in the quantities of other factors. This is clearly seen from the quantity indexes of labour, capital, and materials. Labour input declined by 2.8 percent per year while capital and materials rose by 1.59 and 3.23 percent, respectively. The last two categories of inputs were partially responsible for the increase in agricultural output and yet their partial productivities are found either to be very low or negative. This result illustrates the inadequacy of PFP measures as

Table 6.8: Partial Factor Productivity (PFP) of Labour, Capital, and Materials; Canadian Agriculture, 1961 to 1968 (1971=1.000)

Year	Output Index	L[1] Index	K[1] Index	M[1] Index	PFP(L)	PFP(K)	PFP(M)
1961	.619	1.427	.866	.653	.434	.715	.948
1962	.779	1.373	.874	.668	.567	.891	1.166
1963	.860	1.334	.894	.723	.645	.962	1.189
1964	.809	1.276	.921	.767	.634	.878	1.055
1965	.871	1.188	.955	.801	.733	.744	1.087
1966	.969	1.101	.968	.865	.880	1.000	1.120
1967	.861	1.116	.996	.928	.771	.864	.928
1968	.910	1.065	1.014	.922	.854	.897	.987
1969	.938	1.053	1.023	.919	.891	.917	1.020
1970	.915	.999	1.035	.955	.916	.884	.958
1971	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1972	.948	.929	.999	1.066	1.020	.949	.889
1973	.972	.931	1.019	1.056	1.044	.954	.920
1974	.900	.949	1.075	1.018	.948	.837	.884
1975	.987	.970	1.019	1.037	1.017	.968	.952
1976	1.015	.940	1.152	1.084	1.080	.881	.936
1977	1.044	.895	1.151	1.130	1.166	.907	.924
1978	1.086	.897	1.199	1.196	1.211	.906	.908
Annual Growth Rates(%)							
1961-78	2.01	-2.80	1.59	3.23	4.81	0.69	-1.11
1962-78	1.52	-2.66	1.31	3.09	4.18	0.23	-1.55

[1]L, K, and M refer to labour, capital, and materials.

indicators of overall productivity advance and of the relative importance of various factor inputs in the production process. An input is not increasingly used over a long period if it does not contribute to productivity increase. Yet, according to the PFP approach, an input which increases most rapidly in use shows the least growth in partial productivity.

Energy inputs are becoming increasingly important in Canadian agriculture. The decline in farm labour and the tendency for larger farms have been made possible by the machinery and other mechanical equipment and facilities for both crop and livestock production. This has led to an increase in the use of energy as shown in Table 6.9. Energy issues in Canadian agriculture have been dealt with by some authors (Furniss, 1978; Morris, 1978), but the effect of energy price on the productivity of energy has not been explicitly discussed.

The partial productivity index for energy, defined as the ratio of the index of output to that of energy, shows an annual growth rate of only 0.01 percent. This result demonstrates again the shortcoming of the partial productivity approach. The growth in energy productivity is much slower than the growth in productivity of labour even though the increased use of energy, by enabling mechanization, has contributed to the productivity growth of labour in Canadian agriculture.

Table 6.9: Partial Productivity of Energy, Canadian Agriculture, 1961 to 1978

Year	Output Index	Energy Index	Energy Productivity
1961	.619	.792	.781
1962	.779	.783	.995
1963	.860	.804	1.070
1964	.809	.826	.979
1965	.871	.848	1.027
1966	.969	.865	1.120
1967	.861	.898	.959
1968	.910	.905	1.005
1969	.938	.912	1.028
1970	.915	.935	.979
1971	1.000	1.000	1.000
1972	.948	1.032	.919
1973	.900	1.062	.942
1974	.900	1.073	.837
1975	.987	1.007	.980
1976	1.015	1.018	.997
1977	1.044	1.049	.995
1978	1.086	1.063	1.022
Annual Growth Rate(%)			
1961-78	2.01	1.98	0.01
1962-78	1.52	2.00	-0.45

In a recent paper, Berndt and White (1979) dealt with the interesting issue of the impact of changes in the price of energy on its productivity in the context of the manufacturing industry. Following their framework, the productivity of the i-th input can be defined as output (Y) per unit of input x(i):

$$A(i) = Y/x(i) \tag{6.12}$$

where A(i) is the productivity of the i-th input. From (6.12), the elasticity of productivity of the i-th input with respect to the price of the j-th input price, P(ij), can be written as:

$$P(ij) = \frac{\partial \ln [Y/x(i)]}{\partial \ln P(j)} \tag{6.13}$$

Berndt and White have shown that P(ij) is the negative of the related price elasticity, E(ij). Hence, E(ij)=-P(ij), and E(ii)=-P(ii). Own and cross price elasticities for the various inputs considered in this study were previously reported in Chapter 5. The own price elasticity of energy was found to be -.97 for the homothetic single output model. This implies that a 1 percent increase in energy price will

raise energy productivity by -.97 percent.

An increase in energy price can stimulate an increase in energy productivity through conservation. However, the incentive to save energy depends not only on its own price but also on the prices of other inputs. In fact, as was discussed in Chapter 3, the increase in energy prices was slower than the rise in most farm input prices during the period 1961 to 1978. As a result, energy saving effort in Canadian agriculture was not pursued to any great extent. Moreover, the share of energy in total cost was, and may continue to be, relatively small which may reduce the incentive to economize on energy even with increases in energy price.

Benefits from Productivity Gain

Most studies of productivity tend to concentrate on the extent of productivity gain rather than considering the distribution of this gain. One exception is the study by Lawrence and McKay (1980) which was also concerned with the issue of how much of this benefit accrued to farmers. Their study related to the Australian sheep industry. They used the concept of the terms of trade (defined as the ratio of the index of the price of output (prices received) to the index of prices of inputs (prices paid or imputed)) and as well as the concept of returns to costs (defined as the ratio of the index of value of output to index of the value of inputs). Following Lawrence and McKay, Divisia procedures were used to construct the underlying indexes and the terms

of trade and returns to costs indexes were constructed for Canadian agriculture.

The price indexes of aggregate output and aggregate inputs were constructed using all the components of output and inputs mentioned above. These indexes are reported in columns 1 and 2 of Table 6.10. The ratio of these two indexes is the terms of trade index which is presented in column 3 of the same table. The terms of trade index shows a generally steady decline during the 1960s. In the years of 1972 and 1973, output prices rose much more rapidly than input prices causing the terms of trade to increase markedly. Later in the 1970s the terms of trade deteriorated, largely because of continuous upward increases in input prices. In terms of an annual growth rate for the entire period, the terms of trade declined by 2.65 percent. Such deterioration in the terms of trade is popularly known as the "cost price squeeze". Whether this implies a worsening of the relative position of producers depends on the extent of growth in productivity. That is, one can not say anything definite about changes in the income position of farmers solely from cost-price or terms of trade relationships. Changes in the technical efficiency with which inputs are converted into output--that is, productivity growth--must also be considered.

If productivity improvement is greater than the decline in the terms of trade, the welfare position of producers (defined solely in terms of income generated on the farm)

Table 6.10: Changes in Terms of Trade, Canadian Agriculture, 1961 to 1978

Year	Price Index of Output	Price Index of Input	Terms of Trade
1961	.999	.692	1.444
1962	1.012	.712	1.421
1963	1.015	.735	1.381
1964	1.020	.766	1.332
1965	1.052	.781	1.347
1966	1.088	.830	1.311
1967	1.052	.900	1.169
1968	.993	.936	1.061
1969	1.028	.969	1.061
1970	1.081	.990	1.092
1971	1.000	1.000	1.000
1972	1.298	1.064	1.220
1973	2.083	1.256	1.658
1974	1.980	1.526	1.297
1975	1.806	1.791	1.008
1976	1.744	2.000	.872
1977	1.760	2.093	.841
1978	1.906	2.204	.865
Annual Growth Rates(%)			
1961-78	4.64	7.29	-2.53
1962-78	4.97	7.62	-2.53

can be said to have improved. If, however, deterioration in terms of trade has not been fully offset by increases in productivity, a decline in the relative position of farmers is implied. The concept of returns to costs relates these two measures (Lawrence and McKay, 1980). The relationship can be written as:

$$\begin{pmatrix}\text{Growth Rate of}\\ \text{Returns to Costs}\end{pmatrix} = \begin{pmatrix}\text{Growth Rate of}\\ \text{Productivity}\end{pmatrix} + \begin{pmatrix}\text{Growth Rate of}\\ \text{Terms of Trade}\end{pmatrix} \tag{6.14}$$

The returns to costs ratio index is presented in the last column of Table 6.11. It declines at the annual rate of 0.82 percent from 1961 to 1978. The magnitude of decline is much less than the decline in the terms of trade because the decline in the latter was compensated to a large extent by the productivity increase which occurred at the annual rate of 1.83 percent. The decline in returns to costs was higher--1.35 percent per year--in the period 1962 to 1978 during which productivity growth was lower (1.31 percent).

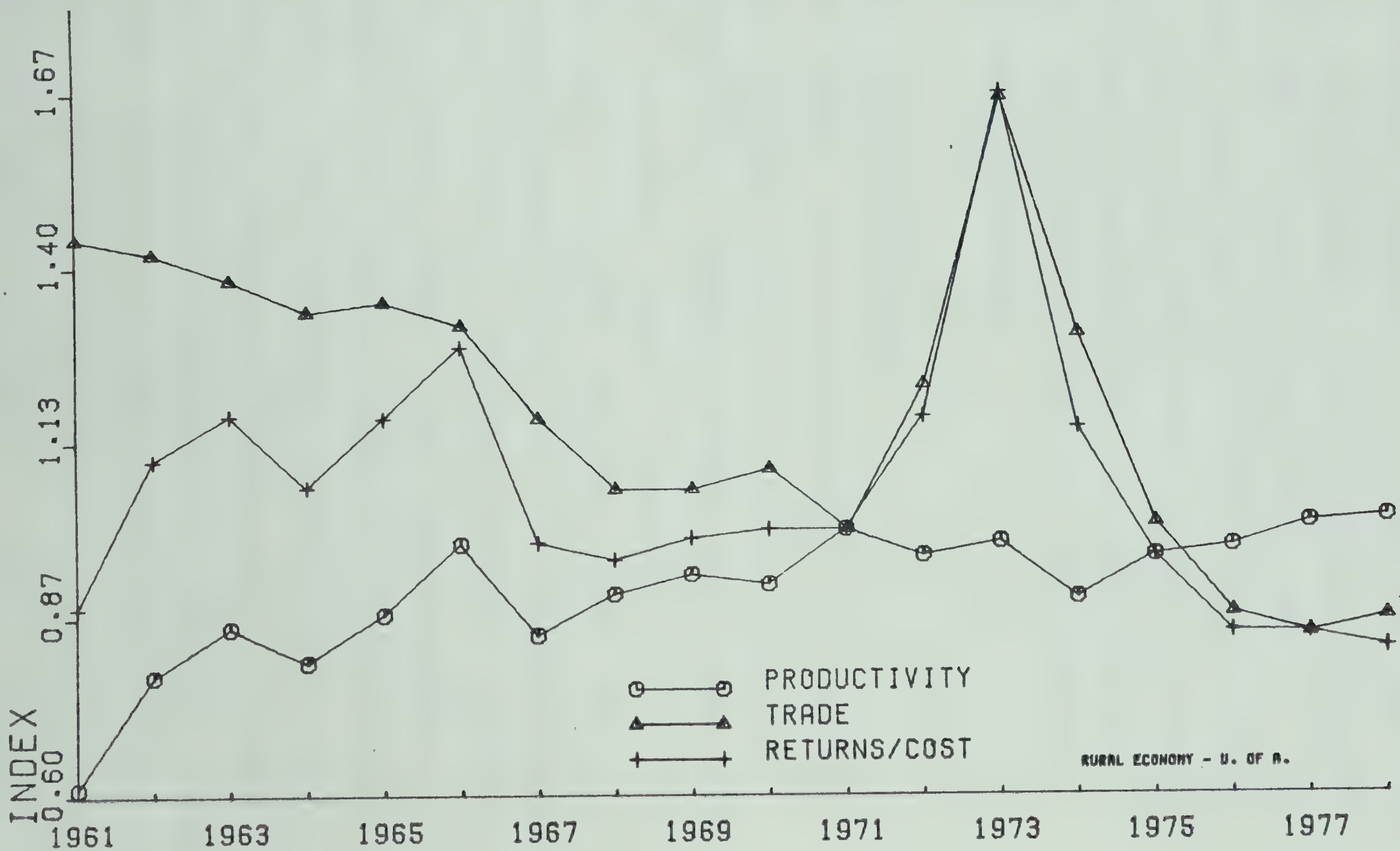
The indexes of productivity, terms of trade, and returns to costs are graphically displayed in Figure 6.3. The terms of trade declined steadily till 1971. The returns to costs index fluctuated widely between 1961 and 1967, and then remained stable till 1971. After 1971, the movements of

Table 6.11: Returns to Costs Ratio, Canadian Agriculture, 1961 to 1978

Year	Productivity	Terms of Trade	Returns to Costs Ratio
1961	.611	1.444	.881
1962	.780	1.421	1.106
1963	.851	1.381	1.174
1964	.800	1.332	1.064
1965	.871	1.347	1.170
1966	.978	1.311	1.278
1967	.840	1.169	.980
1968	.902	1.061	.954
1969	.932	1.061	.987
1970	.917	1.092	1.000
1971	1.000	1.000	1.000
1972	.960	1.220	1.172
1973	.981	1.658	1.665
1974	.896	1.297	1.155
1975	.960	1.008	.960
1976	.974	.872	.844
1977	1.010	.841	.842
1978	1.018	.865	.820
Annual Growth Rates(%)			
1961-78	1.83	-2.53	-0.82
1962-78	1.31	-2.53	-1.35

FIGURE 6.3: TOTAL FACTOR PRODUCTIVITY, TERMS OF TRADE, AND RETURNS TO COSTS.

CANADIAN AGRICULTURE, 1961 TO 1978 (1971=1.000)



terms of trade and returns to costs were almost identical.

A decline in the returns to costs ratio over the entire period could give an indication that the welfare position of producers has deteriorated. In reality, however, the income position of farmers is a much more complex issue, complicated by the considerable off-farm income earned by many farm families and by the question of capital gains. Furthermore, there is some indication that the relative income levels of some farmers, especially grain farmers, have been stronger since 1972.

E. Estimates for Western Canada

In this section, estimates of productivity growth in agriculture in Western Canada are presented. A separate study of productivity in Western Canadian agriculture may prove useful for several reasons. The growth rate of agricultural output in Western Canada was higher than in Canada during the period 1961 to 1978. The important issues considered here are whether this higher growth in output is attributable to higher growth in input usage or higher growth in productivity (or to a combination of both) and whether farmers' terms of trade and returns to costs have moved differently at the Western Canadian level. A related issue which is emphasized in this study is the use of energy and its productivity and the likely impact of an increase in the price of energy and the efficiency of its use in Western Canada. The components of the indexes of outputs and inputs,

as well as the methods of analysis and data construction, are the same as those used for Canada as a whole.

Indexes of Output, Inputs, and Productivity

Total factor productivity (TFP) estimates for Western Canada were generated from indexes of aggregate output and inputs which are reported in Table 6.12 and Table 6.13, respectively. The aggregate output index, in turn, is based on a weighted composite of the index of crop production and the index of livestock production for Western Canada. The index of crop production shows wide ranging fluctuations with annual growth rates of 4.04 and 2.90 percent for the periods of 1961 to 1978 and 1962 to 1978, respectively. The influence of the year 1961 is more pronounced in the case of Western Canada for crop production than livestock production. This is to be expected since the drought of 1961 in the Prairie provinces caused crop failure. The growth rates in livestock production were much slower than for crop production: livestock production grew at 1.36 and 1.41 percent for the two periods of 1961 to 1978 and 1962 to 1978, respectively. The index of all output is given in the last column of Table 6.12. The annual growth rate of the index of aggregate output was 3.27 percent over 1961 to 1978 and somewhat lower at 2.52 percent from 1962 to 1978. These growth rates are higher than the corresponding growth rates for Canada as a whole (2.01 and 1.52 percent).

The indexes of various broad categories of farm inputs and of total farm inputs are reported in Table 6.13. The

Table 6.12: Divisia Quantity Indexes of Agricultural Output, Western Canada, 1961 to 1978 (1971=1.000)

Year	Crops	Livestock	All Output
1961	.364	.856	.477
1962	.681	.812	.723
1963	.826	.806	.836
1964	.679	.874	.733
1965	.810	.907	.846
1966	.964	.899	.967
1967	.713	.922	.774
1968	.842	.940	.879
1969	.770	.893	.809
1970	.803	.941	.842
1971	1.000	1.000	1.000
1972	.902	1.011	.934
1973	.947	1.004	.964
1974	.807	.997	.854
1975	.981	.989	.997
1976	1.114	1.019	1.110
1977	1.141	1.053	1.138
1978	1.264	1.038	1.223
<u>Annual Growth Rates</u>(%)			
1961-78	4.04	1.36	3.27
1962-78	2.90	1.41	2.52

Table 6.13: Divisia Quantity Indexes of Farm Inputs, Western Canada, 1961 to 1978 (1971=1.000)

Year	Capital	Labour[1]	Materials	All Inputs
1961	.888	1.275	.601	.962
1962	.886	1.274	.629	.969
1963	.903	1.279	.662	.986
1964	.928	1.261	.720	1.004
1965	.960	1.154	.752	.985
1966	.975	1.077	.837	.983
1967	1.005	1.075	.928	1.015
1968	1.003	.947	.948	.976
1969	1.034	1.050	.899	1.011
1970	1.050	.962	.933	.987
1971	1.000	1.000	1.000	1.000
1972	1.027	.967	1.072	1.010
1973	1.041	.927	1.120	1.008
1974	1.097	.899	1.123	1.016
1975	1.138	.961	1.117	1.054
1976	1.204	1.047	1.169	1.126
1977	1.191	.982	1.272	1.113
1978	1.212	1.007	1.305	1.138
Annual Growth Rates (%)				
1961-78	1.82	-1.79	4.49	0.79
1962-78	1.84	-1.71	4.35	0.82

[1]The labour data are based on manhours and not on persons employed.

index of total farm inputs increased at a compound annual growth rate of 0.79 percent over 1961 to 1978. This is the result of yearly increases in capital and materials of 1.82 and 4.49 percent, respectively, and an annual decline of 1.80 percent in the labour input. The growth rate in the index of all inputs is higher for Western Canada (0.79 percent) than for Canada (0.19 percent). The higher growth rate appears to be the result of larger increases in capital and material inputs and smaller declines in the labour input. In Western Canada, labour (measured in manhours) declined by 1.80 percent per year while for Canada the figure was 2.80 percent.

The TFP index for Western Canada is presented in Table 6.14. TFP grew at an annual rate of 2.48 percent during the time period 1961 to 1978. This is the residual difference between the growth rate in output of 3.27 percent and the growth rate in inputs of 0.79 percent. When the drought year of 1961 is excluded, the growth rate of TFP falls to 1.70 percent.

The growth rates of TFP for the period 1962 to 1978 are more realistic estimates than those for 1961 through 1978 because of the upward bias imparted by the fact that 1961 was an abnormally poor crop year. The estimated growth rate of TFP for Western Canada (1.7 percent over 1962-1978) is higher than that estimated for Canada (1.3 percent over the same period). The higher rate of growth in productivity at the Western Canadian level is associated with a higher

Table 6.14: Indexes of Output, Inputs and Total Factor Productivity, Western Canada, 1961 to 1978 (1971=1.000)

Year	Output	Inputs	Productivity
1961	.477	.962	.496
1962	.723	.969	.746
1963	.836	.986	.848
1964	.733	1.004	.730
1965	.846	.985	.859
1966	.967	.983	.984
1967	.774	1.015	.762
1968	.879	.976	.901
1969	.809	1.011	.800
1970	.842	.987	.853
1971	1.000	1.000	1.000
1972	.934	1.010	.925
1973	.964	1.008	.956
1974	.854	1.016	.840
1975	.997	1.054	.956
1976	1.110	1.126	.986
1977	1.138	1.113	1.022
1978	1.223	1.138	1.075
Annual Growth Rates(%)			
1961-78	3.27	0.79	2.48
1962-78	2.52	0.82	1.70

growth in aggregate output which more than compensated for a higher rate of growth in aggregate input use. In part, then, the higher growth rate in Western Canada is likely attributable to the greater importance of the grain sector in Western Canada, the grain boom in the mid-1970s, and the attendant impetus for the adoption of further mechanical and biological technology in the grains sector.

Annual growth rates of TFP in percentage terms for Western Canada in different subperiods were also obtained and are reported below:

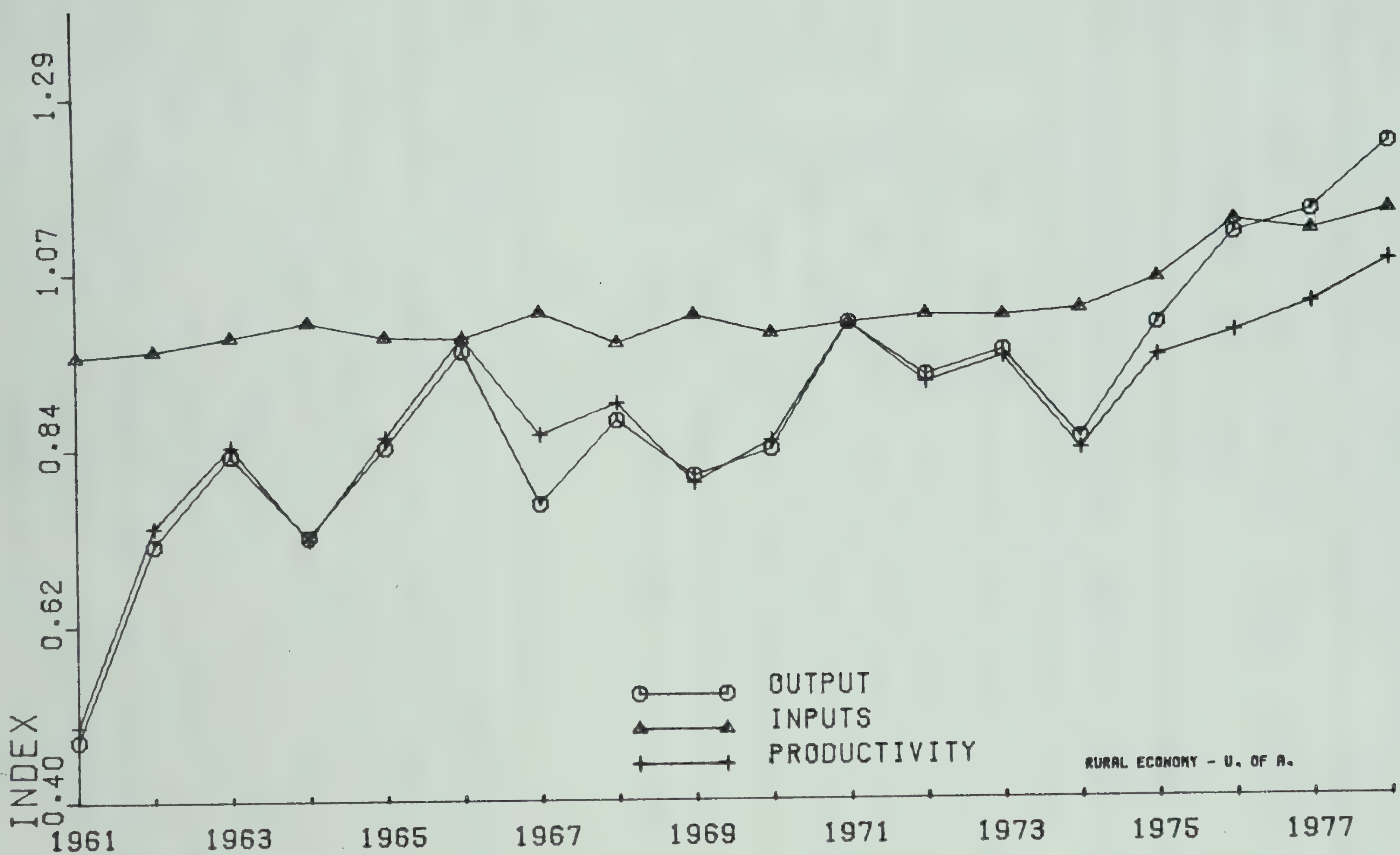
1962-70	1.10
1962-71	1.84
1962-72	1.81
1971-78	1.47
1972-78	2.69
1973-78	3.50

The estimates of productivity growth in Western Canada for the later periods are higher than the corresponding Canadian estimates. Compared to the earlier periods, Western Canada also registered higher productivity growth in the later periods. This is in contrast to the situation in Canada as a whole, where there were some indications of slower productivity growth in the later periods.

The indexes of aggregate output, inputs, and total factor productivity are graphically represented in Figure 6.4. The aggregate input index rose gradually and slowly,

FIGURE 6.4: INDEXES OF AGRICULTURAL OUTPUT, INPUTS AND TOTAL FACTOR PRODUCTIVITY,

WESTERN CANADA, 1961 TO 1978 (1971=1.000)



while fluctuations in the productivity index were more pronounced and tended to follow the fluctuations in the output index. It is only during the last few years that output growth has been greater than productivity growth and this faster growth in output has been a result of faster growth in the aggregate input index.

Productivity growth rates based on the Laspeyres index were also obtained for Western Canada. Laspeyres indexes and annual growth rates are reported in Table 6.15. For the period 1961 to 1978, the annual growth rate was 2.51 percent which happens to be very close to the Divisia growth rate of 2.48 percent. When the drought year of 1961 was excluded, the Laspeyres based annual growth rate fell to 1.80 percent which is slightly higher than the Divisia based growth rate of 1.70 percent. The Western Canadian estimates based on these two indexing procedures appeared much closer than for Canada.

The Star-Hall method--a shortcut procedure of estimating the growth rate of TFP using only endpoint data--was also applied for the agricultural sector of Western Canada. The Star-Hall estimates of the annual growth rates of TFP, based on Tables 6.12, 6.13, and 6.16 for the two periods of 1961 to 1978 and 1962 to 1978 are 2.04 and 1.40 percent, respectively. These estimates are somewhat lower than the standard Divisia estimates, but they might serve as first order approximations of productivity growth where insufficient data exists to compute Divisia estimates.

Table 6.15: Laspeyres Based Indexes of Agricultural Output, Inputs, and Total Factor Productivity, Western Canada, 1961 to 1978 (1971=1.000)

Year	Output	Inputs	Productivity
1961	.503	.992	.507
1962	.720	.997	.722
1963	.820	1.012	.810
1964	.734	1.025	.716
1965	.837	.998	.839
1966	.946	.989	.956
1967	.772	1.018	.758
1968	.870	.974	.893
1969	.805	1.011	.796
1970	.842	.986	.854
1971	1.000	1.000	1.000
1972	.933	1.011	.923
1973	.963	1.009	.954
1974	.861	1.018	.846
1975	.983	1.057	.930
1976	1.087	1.129	.963
1977	1.116	1.119	.997
1978	1.200	1.144	1.049
Annual Growth Rates(%)			
1961-78	3.15	0.64	2.51
1962-78	2.49	0.69	1.80

Table 6.16: Shares of Capital, Labour, and Materials in Total Cost, Western Canada, 1961 to 1978

Year	Total Cost[1]	Capital	Labour	Materials
1961	1489.6	.2915	.5229	.1855
1963	1649.1	.2986	.5099	.1914
1964	1769.3	.3365	.4683	.1950
1965	1819.6	.3707	.4320	.1971
1966	1883.2	.3679	.4194	.2126
1967	2156.9	.3691	.4186	.2123
1968	2173.6	.3944	.3841	.2215
1969	2302.8	.3747	.4286	.1967
1970	2235.9	.3752	.3868	.1951
1971	2303.2	.3544	.4287	.2169
1972	2465.5	.3570	.4214	.2216
1973	2797.9	.3559	.3949	.2491
1974	3458.1	.3578	.3740	.2682
1975	4248.9	.3576	.3914	.2506
1976	5322.0	.3818	.3964	.2218
1977	5741.6	.3938	.4443	.2406
1978	6303.2	.3801	.4051	.2147

[1]Both actual and imputed costs are included and reported in terms of millions of current dollars.

Partial Factor Productivity

The indexes of partial productivities of the three broad categories of inputs--labour, capital, and materials--are reported in Table 6.17. The productivity of labour and capital grew by 5.14 percent and 1.37 percent per year, respectively, while that of materials declined by 1.17 percent. As expected, all growth rates of partial productivity indexes fell when the drought year 1961 was excluded.

The partial factor productivity measures again give paradoxical indications of productivity gains. The productivity of labour is found to be higher than the productivity of capital although the latter input contributed to the increase in output from the declining input of labour. Of the three categories of inputs, materials exhibited the highest rate of growth of use. This category of inputs likely contributed to the increase in output and yet its partial productivity was found to be negative. This is because the rate of growth of the index of the material inputs was higher than the growth in output.

The measure of partial productivity of energy (one of the subcomponents of the material input) is of particular interest. The quantity index of energy and the partial productivity of energy are reported in Table 6.18. The use of energy increased at the yearly rate of 2.67 percent in Western Canada between 1961 and 1978. This rate is higher than that for Canada (1.98 percent--see Table 6.9) as a

Table 6.17: Partial Factor Productivity (PFP) of Labour, Capital, and Materials; Western Canada, 1961 to 1978 (1971=1.000)

Year	Output	L[1]	K[1]	M[1]	PFP(L)	PFP(K)	PFP(M)
1961	.477	1.275	.888	.601	.374	.537	.797
1962	.723	1.247	.886	.629	.567	.816	1.149
1963	.836	1.279	.903	.662	.654	.926	1.263
1964	.733	1.261	.928	.720	.581	.790	1.018
1965	.846	1.154	.960	.752	.733	.881	1.125
1966	.967	1.077	.975	.837	.898	1.077	1.155
1967	.774	1.075	1.005	.928	.720	.770	.834
1968	.879	.947	1.003	.947	.928	.876	.928
1969	.809	1.050	1.034	.899	.770	.782	.900
1970	.842	.962	1.050	.933	.875	.802	.902
1971	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1972	.934	.967	1.027	1.071	.966	.909	.872
1973	.964	.927	1.041	1.120	1.140	.926	.861
1974	.854	.899	1.097	1.123	.950	.778	.760
1975	.997	.961	1.138	1.117	1.037	.876	.892
1976	1.110	1.047	1.204	1.169	1.060	.922	.949
1977	1.138	.982	1.191	1.272	1.159	.955	.895
1978	1.228	1.007	1.212	1.305	1.214	1.009	.937
Annual Growth Rates (%)							
1961-78	3.27	-1.79	1.82	4.49	5.14	1.37	-1.17
1962-78	2.52	-1.71	1.84	4.35	4.27	0.59	-1.79

[1]L, K, and M refer to labour, capital, and materials.

Table 6.18: Partial Productivity of Energy, Western Canada, 1961 to 1978 (1971=1.000)

Year	Output Index	Energy Index	Energy Productivity
1961	.477	.765	.623
1962	.723	.771	.938
1963	.836	.787	1.062
1964	.733	.809	.906
1965	.846	.846	1.000
1966	.967	.864	1.143
1967	.774	.922	.839
1968	.879	.930	.945
1969	.809	.936	.864
1970	.842	.964	.873
1971	1.000	1.000	1.000
1972	.934	1.032	.905
1973	.964	1.076	.896
1974	.854	1.149	.743
1975	.997	1.070	.932
1976	1.110	1.094	1.015
1977	1.138	1.144	.995
1978	1.223	1.163	1.051
Annual Growth Rates(%)			
1961-78	3.27	2.67	0.59
1962-78	2.52	2.67	-0.17

whole. Faster growth in the use of energy in Western Canada might be attributable to such factors as the greater importance of grain farming in the farm enterprise mix and the slightly lower levels of energy price which have prevailed in Western Canada.

The index of partial productivity of energy, given in the last column of Table 6.18, shows an annual rate of growth of only 0.59 percent from 1961 to 1978. For the period from 1962 to 1978, when the growth rate in output was much lower, the rate of growth of productivity was negative(-0.17 percent). These estimates are similar to the ones obtained for Canada and illustrate the shortcomings of the PFP approach.

The link between the price of an input and its productivity was noted in equation (6.17) above. This relationship means that the elasticity of the productivity is the negative of the corresponding price elasticity of demand. The estimated translog own price elasticity of demand for energy for Western Canada in the homothetic single output model is -0.72. This implies that the elasticity of the productivity of energy is 0.72. In other words, an increase in the price of energy of 1 percent would raise energy productivity by 0.72 percent in Western Canada. This productivity value is lower than that obtained for Canada.

Benefits from Productivity Gain

As was the case for Canada as a whole, two concepts are used to gain an indication of the distribution of productivity gains in Western Canada: changes in farmers' terms of trade (the ratio of the price of output to the price of input) and changes in farmers' returns to costs ratio (the ratio of the value of the output to the value of input).

The terms of trade of Western Canadian agricultural producers generally declined during the 1960s and 1970s. Despite considerable recovery during 1973-75, farmers' terms of trade fell by 2.40 percent per year from 1961 to 1978 as a result of a 7.56 percent increase in the price of input and a 5.03 percent increase in the price of output. For the period 1962 to 1978, the annual rate of decline was 2.32 percent. The foregoing estimates are reported in Table 6.19.

It was pointed out in the previous discussion that the decline in farmers' terms of trade should be weighed against productivity growth to arrive at a more definite conclusion of whether there has been a deterioration in farmers' economic position. The concept of returns to costs links these two aspects. Returns to costs ratios, presented in Table 6.20, show a very slow growth rate of 0.12 percent per year during the period 1961 to 1978. The benefits of productivity gain (2.48 percent) were almost totally counterbalanced by the declining terms of trade (-2.40 percent). For the period 1962 to 1978, when productivity

Table 6.19: Changes in Terms of Trade, Western Canada, 1961 to 1978 (1971=1.000)

Year	Price Index of Output	Price Index of Inputs	Terms of Trade
1961	1.019	.672	1.516
1962	1.094	.701	1.561
1963	1.056	.726	1.454
1964	1.085	.765	1.418
1965	1.046	.802	1.304
1966	1.098	.832	1.320
1967	1.149	.922	1.240
1968	1.089	.967	1.126
1969	1.020	.989	1.031
1970	.974	.983	.991
1971	1.000	1.000	1.000
1972	1.018	1.060	.960
1973	1.493	1.205	1.239
1974	2.409	1.478	1.630
1975	2.325	1.749	1.329
1976	2.192	2.052	1.068
1977	1.964	2.239	.877
1978	2.084	2.404	.867
Annual Growth Rates(%)			
1961-78	5.03	7.55	-2.40
1962-78	5.41	7.86	-2.32

Table 6.20: Returns to Costs Ratio, Western Canada, 1961 to 1978 (1971=1.000)

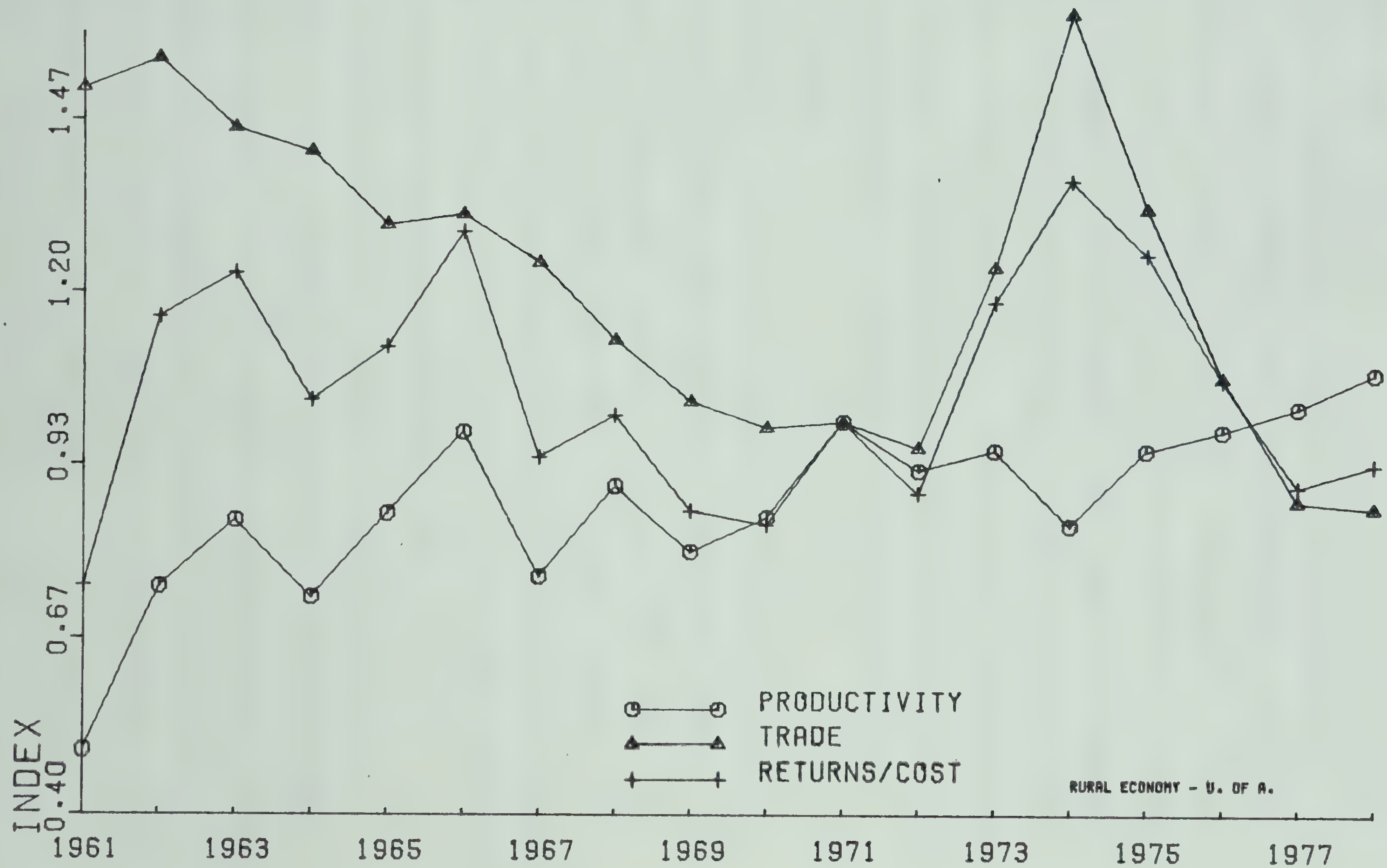
Year	Productivity	Terms of Trade	Returns to Costs Ratio
1961	.496	1.516	.748
1962	.746	1.561	1.162
1963	.848	1.454	1.230
1964	.730	1.418	1.033
1965	.859	1.304	1.116
1966	.984	1.320	1.294
1967	.762	1.246	.946
1968	.901	1.126	1.010
1969	.800	1.031	.863
1970	.853	.991	.842
1971	1.000	1.000	1.000
1972	.925	.960	.890
1973	.956	1.239	1.185
1974	.840	1.630	1.373
1975	.956	1.329	1.259
1976	.986	1.068	1.064
1977	1.022	.877	.900
1978	1.075	.867	.934
Annual Growth Rates(%)			
1961-78	2.48	-2.40	0.12
1962-78	1.70	-2.32	-0.57

growth was slower (1.70 percent), the returns to costs ratio declined by 0.57 percent per year.

A graphical representation of the terms of trade and returns to costs indexes for Western Canada is given in Figure 6.5. It can be seen that the terms of trade index fell secularly between 1961 and 1971, after which it rose sharply till 1973 and then fell again. The returns to costs index widely fluctuated before 1971, rose steeply till 1973, and then fell again. The post-1971 movements in terms of trade and returns to costs were very close.

The trend in the distribution of productivity gains seen above is similar to that outlined earlier for Canada. The magnitude of the decline in farmers' economic position, as given by returns to costs estimates, is smaller in the case of Western Canada because of the faster growth of output and productivity in the region. If higher productivity can be maintained and increased in the future, the decline in farmers' relative position may be reversed; otherwise, the erosion of productivity gain by adverse terms of trade may become more severe in Western Canada. The necessary caveat to this discussion of farmers' relative position is that it relates only to income generated on the farm and neglects consideration of either off-farm income or capital gains, two major contributors to the current welfare position of farmers.

FIGURE 6.5: TOTAL FACTOR PRODUCTIVITY, TERMS OF TRADE, AND RETURNS TO COSTS IN AGRICULTURE, WESTERN CANADA, 1961 TO 1978 (1971=1.000)



F. Summary

The major empirical results of this chapter are summarized below:

1. In Canadian agriculture, total factor productivity (TFP), based on manhours data, increased by 1.31 per year between 1962 and 1978 (or at the upwardly biased rate of 1.82 percent per year between 1961 and 1978). In Western Canada, the TFP growth rate, based on manhours data, was 1.70 percent per year between 1962 and 1978 (or 2.48 percent between 1961 and 1978). In general, the estimates of productivity growth are somewhat sensitive to the conceptual and empirical measurement of the labour input.
2. Growth rates in TFP in Canada for different subperiods indicate some decline in the latter periods--for example, 2.12 percent between 1962 and 1972, and 1.61 percent between 1973 and 1978. In Western Canada, on the other hand, TFP growth rates in the latter periods were higher--for example, 1.81 percent between 1962 and 1972, and 3.50 percent between 1973 and 1978.
3. The estimates of partial factor productivity (PFP) showed that the productivity of labour increased the most followed by that of capital and materials. Thus the inputs which replaced labour appeared less productive than labour. The growth rate of partial productivity of energy was found to be either very low or negative. Partial productivity trends in Canada and Western Canada

were similar.

4. The Star-Hall approximation, using only endpoint data, generated TFP growth rates which were reasonably close to those generated by considering data for all years. The differences between the Star-Hall and Divisia based growth rates are caused by fluctuating input cost shares.
5. The relationship between energy price and energy productivity (using the Berndt-White framework) showed that the productivity of energy was sensitive to energy price changes. The magnitude of this sensitivity depended on the own price elasticity of demand for energy.
6. The growth rate in the terms of trade (ratio of the indexes of prices received to prices paid) was observed to be negative over the period 1962 to 1978 in both Canadian and Western Canadian agriculture. The growth rate in the returns to costs ratio (ratio of the indexes of the value of output to the value of inputs), which is the sum of the growth rates in productivity and terms of trade, was also found to be negative over the same periods. The decline in the returns to costs measure indicates a deterioration in farmers' economic position based on their on-farm income.

VII. SUMMARY, CONCLUSIONS, AND IMPLICATIONS

A. Summary and Conclusions

This study dealt with various aspects of factor substitution and productivity change in Canadian and Western Canadian agriculture. The study of factor substitution was conducted using derived input demand functions corresponding to various modifications of the translog cost function defined for the inputs of land, labour, machinery, fertilizer, and energy. Technical change was incorporated by including time as an argument in the cost function.

The empirical estimates of the Allen elasticities of substitution (AES) showed considerable factor substitution (and complementarity) in both Canadian and Western Canadian agricuture. The estimates of AES for different subperiods changed in magnitude but not in sign. There was also no indication of a decline in capital (machinery)-labour substitution in Canadian and Western Canadian agriculture between the the periods of 1961-73 and 1974-78. This implied that the 'energy crisis' did not have any significant dampening effect on capital-labour substitution in Canadian agriculture. The own price elasticities of demand (ED) were generally found to be less than one indicating inelastic demand for most farm inputs. The translog values of ED differed substantially from the corresponding Cobb-Douglas values which were also reported.

In Canadian agriculture, the existence of technical change was observed for both homothetic and nonhomothetic models, while in Western Canada, technical change was observed only in the homothetic model. In both Canada and Western Canada, there was evidence of labour-saving and machinery-using, and fertilizer-using bias in technical change. The importance of the purchased inputs (materials) and the interdependence between these and the durable inputs were confirmed through the rejection of the stringent conditions of the value added specification.

The empirical estimates of factor substitution suggest that input use in Canadian agriculture was shaped by the forces of changing relative input prices and technical change as well as (though to a lesser extent) by scale effects. The picture of changing input use which emerged is more complicated than that implied by the Cobb-Douglas and the CES functions which restrict the value of elasticities of substitution to unitary or nonnegative values.

In the study of productivity, the flexible weight Divisia indexing method was used. This procedure takes into consideration factor substitution and differs from the Laspeyres index which regards all subcomponents as perfect substitutes. The empirical estimates of productivity growth varied from 1.01 to 1.82 percent for Canadian agriculture depending on the definition of labour (persons employed or manhours) used and the inclusion or exclusion of the drought year, 1961. For Western Canada, the growth rate of

productivity based on manhours data was found to be higher than that of Canada. The Star-Hall method of approximation generated growth rates of total factor roductivity which were similar to the Divisia based estimates.

The partial factor productivity (PFP) estimates for various farm inputs were also reported. The shortcomings of the PFP approach were clear from the empirical estimates which showed that growth rates of partial productivity of the inputs capital and materials were very low or negative, while that of labour, whose use declined relatively, was very high. The relationship between energy price and energy productivity was examined using the framework proposed by Berndt and White (1979). This showed that energy productivity was sensitive to energy price change.

The benefits of productivity growth were assessed by considering both changes in farmers' terms of trade (popularly known as the "cost price squeeze") and returns to costs. The decline in the terms of trade was greater than the decline in productivity growth, resulting in a decline in returns to costs. These estimates indicated that farmers' economic position based on on-farm income deteriorated over the period of 1962 to 1978 in Canada and, to a lesser extent, in Western Canada.

B. Recommendations and Possible Extensions

This study outlines and illustrates improved theoretical and empirical approaches to studies of both input substitution and productivity growth in Canadian agriculture. Given these improvements, it is recommended that particular attention be paid in future to further improvement of the basic data series, especially input series, which underlie this work. Studies of factor substituton and productivity change in Canadian agriculture will be greatly facilititated if Statistics Canada provides more complete manhours data on a yearly basis, and price and quantity data on fertilizer and its various components (N, P, K). In this study, the 1976 census definition of a farm has been used. As an alternative, the 1961 census definition could be used in measuring the land input. The use of the 1961 definition is likely to lower the growth of the aggregate input index and generate a slightly higher growth rate of TFP. As well, in imputing opportunity cost to the capital input (land and machinery), a flexible interest rate might be used (Ellahi, 1981).

In the area of agricultural productivity, Statistics Canada should take the lead in (a) providing total factor productivity indexes for agriculture in Canada and its various regions, and (b) using the Divisia indexing method which has been advocated for productivity analysis by the United States Department of Agriculture (1980) and by academic researchers (Jorgenson and Griliches, 1967;

Christensen, 1975; Brown, 1978). Further extensions in productivity research in Canada might involve the correction of output (and thence productivity) for climatic changes and the attempt to account for the sources of productivity growth.

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